Direct photons – experimental status

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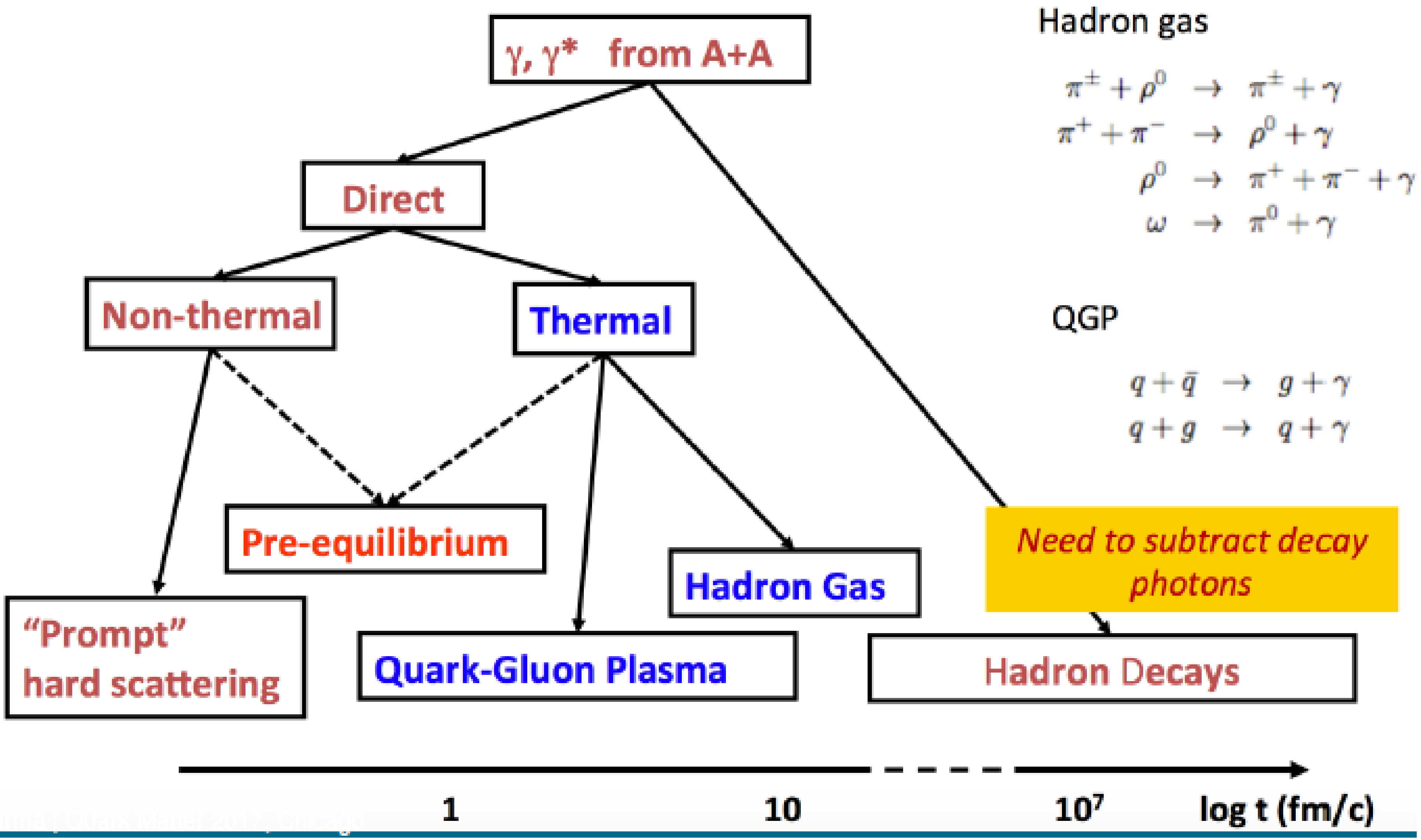
Easy: QM'17 finished 4 days ago, just recapitulate…

Hard: you probably were there, and don't want to get bored

So I'm trying to add a few twists ☺

Photon sources vs time in collision



Differential measurements – in principle

Sources	p_T	v_2	v_3	v_n t-dep.
Hadron-gas	Low p_T	Positive and sizable	Positive and sizable	
QGP	Mid p_T	Positive and small	Positive and small	
Primordial (jets)	High p_T	~zero	~zero	
Jet-Brems.	Mid p_T	Positive	?	
Jet-photon conversion	Mid p_T	Negative	?	
Magnetic field	All p_T	Positive down to p_T=0	Zero	

All quiet on the high p_T front (so far)

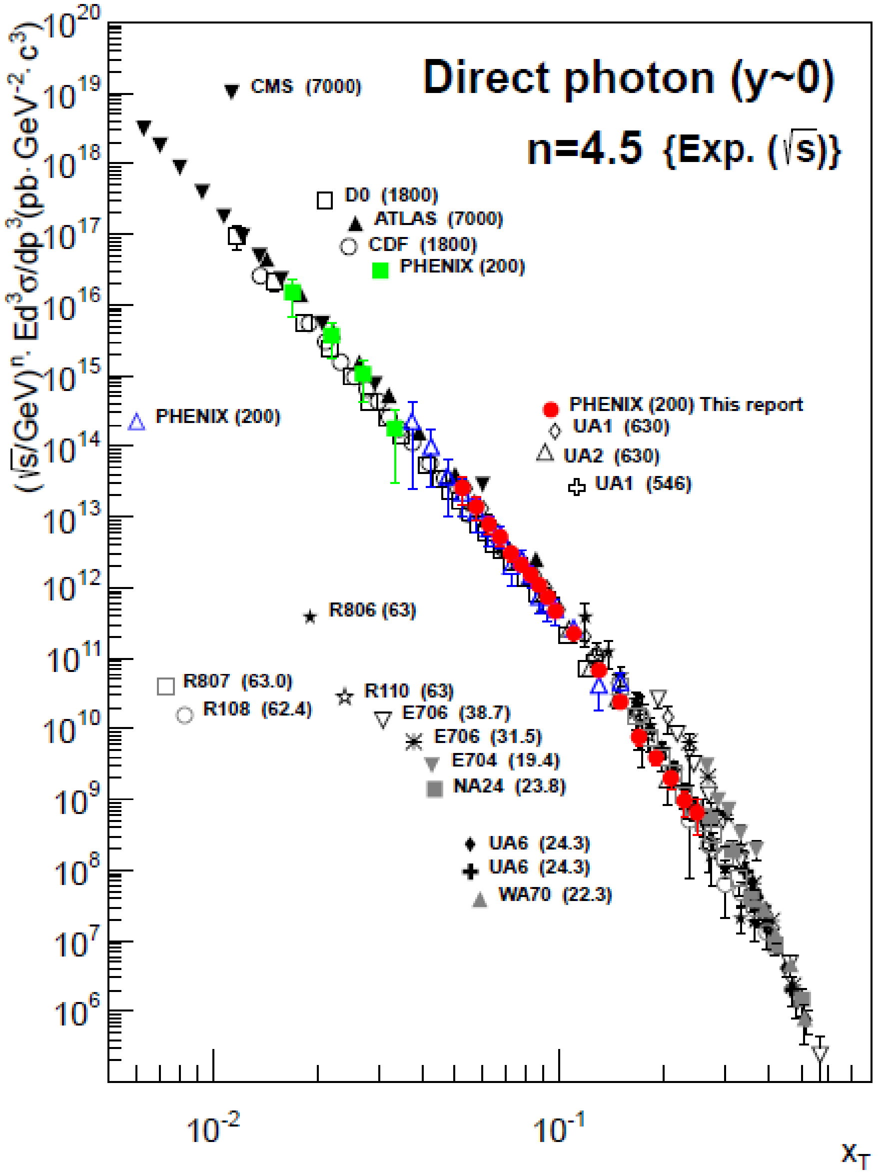
PRD 86 072008 (2012)

pp reference – world data (as of 2012)

19.4 – 7000 GeV, 12+ o.m. in cross section

well described by theory

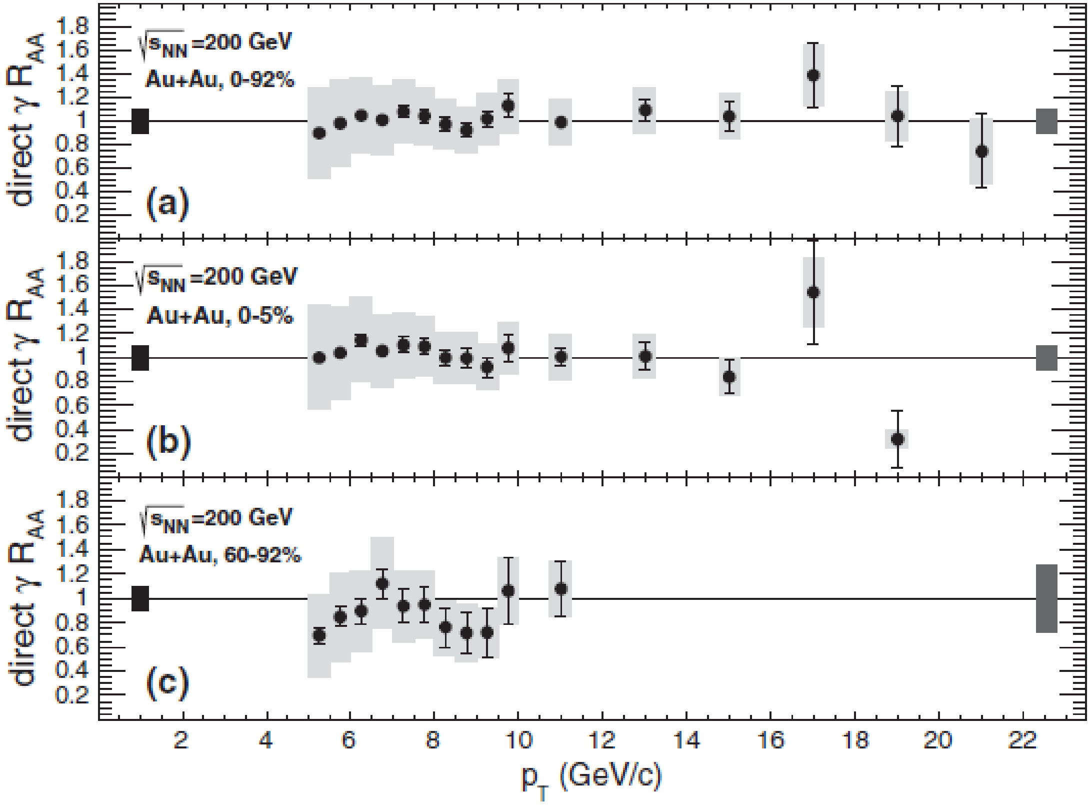
reference for heavy ions, modulo
-- isospin (p,n) effects
-- jet-photon conversion
(fast parton + thermal medium)



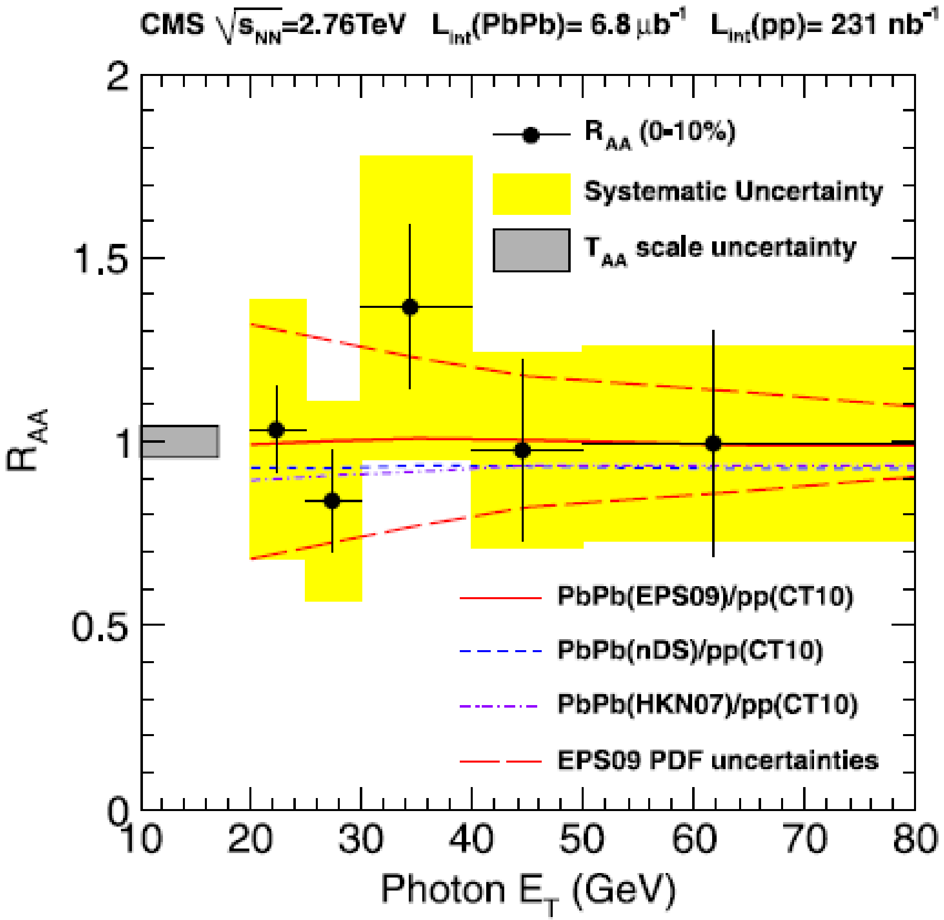
High p_T photons in A+A collisions (old news)

In A+A collisions, while hadrons are strongly suppressed, and in a p_T-dependent way, photons appear to be unaffected

PHENIX (PRL 109, 152302 (2012))

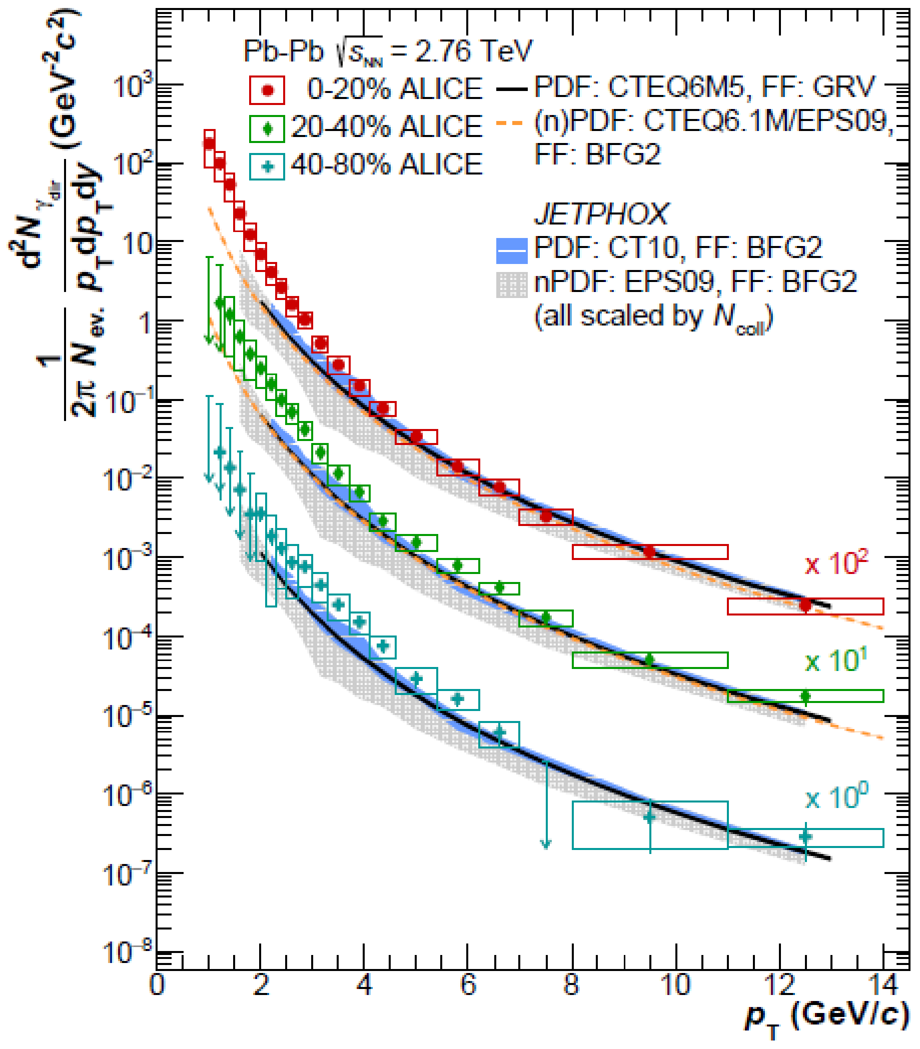


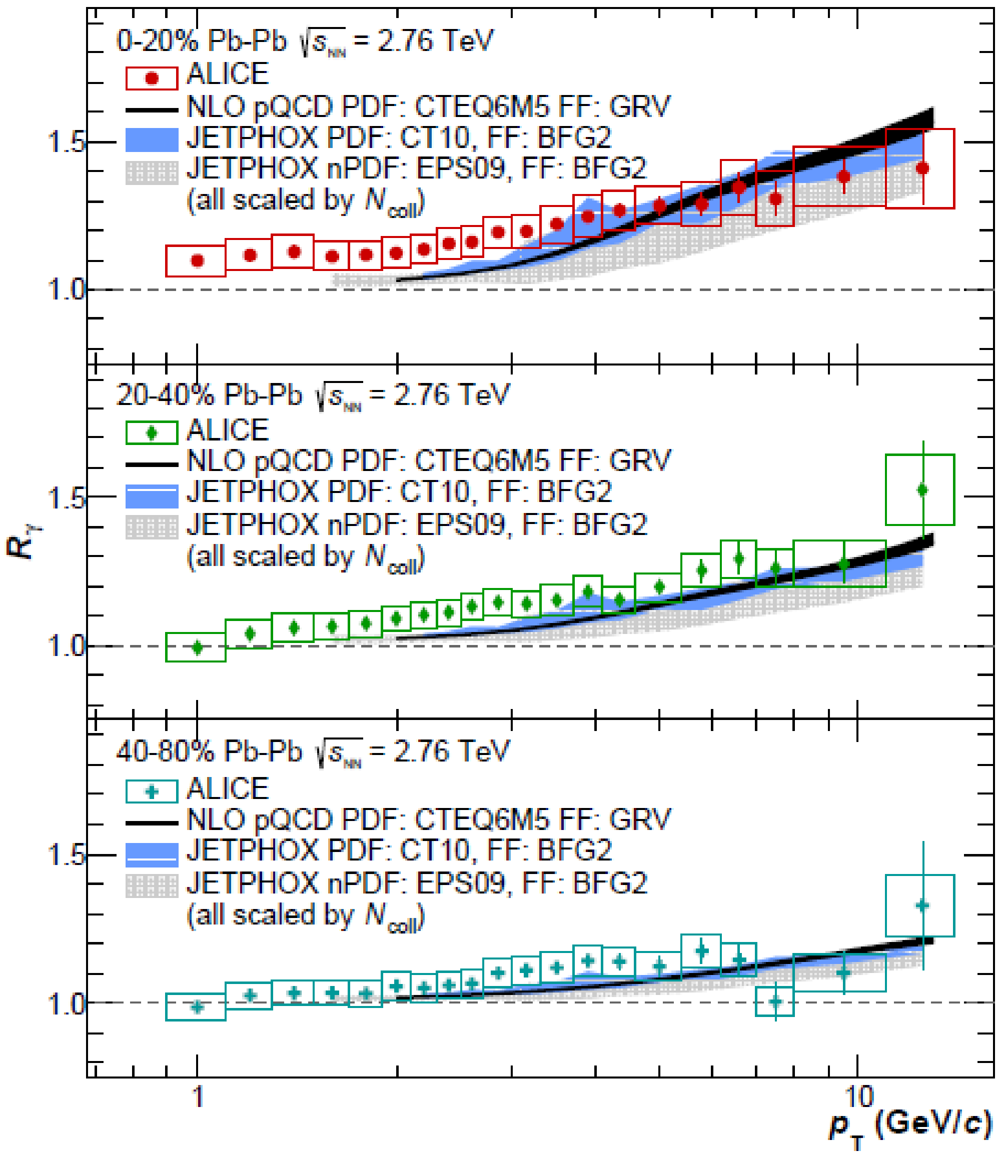
CMS (PLB 710 (2012) 256)
isolated photons, PbPb 0-10% centrality



High p_T photons in A+A collisions (old news)

ALICE (PLB 754, 235 (2016))



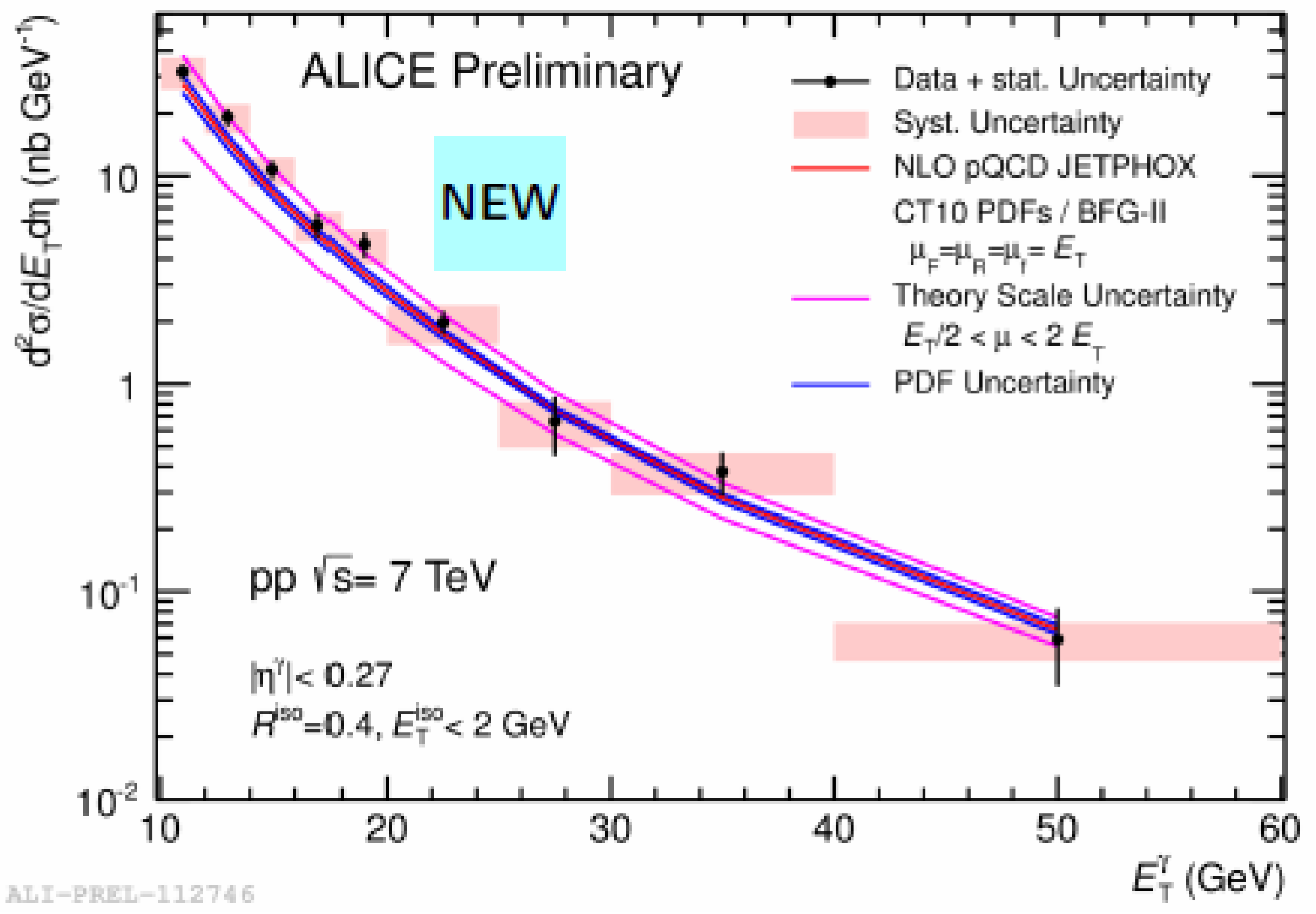


High p_T photons in p+p collisions (new news)

Isolated photons, 7 TeV pp, ALICE

- Shower Shape for $\pi^0 \to \gamma\gamma$ rejection:
  $\sigma^2_{\text{long}} = 0.5\left(\sigma^2_{\varphi\varphi} + \sigma^2_{\eta\eta} + \sqrt{(\sigma_{\varphi\varphi} - \sigma_{\eta\eta})^2 + 4\sigma^2_{\eta\varphi}}\right)$

cone with radius $R = \sqrt{\Delta\varphi^2 + \Delta\eta^2} = 0.4$ around photon candidate
Isolated if: $\sum^{in\ cone}_{charged,neutral} p_{\mathrm{T}} \leq p_{\mathrm{T}}^{thres} = 2$ GeV/c



A cautionary tale on the golden channel – γ - jet

822 Eur. Phys. J. C (2009) 61: 819–823

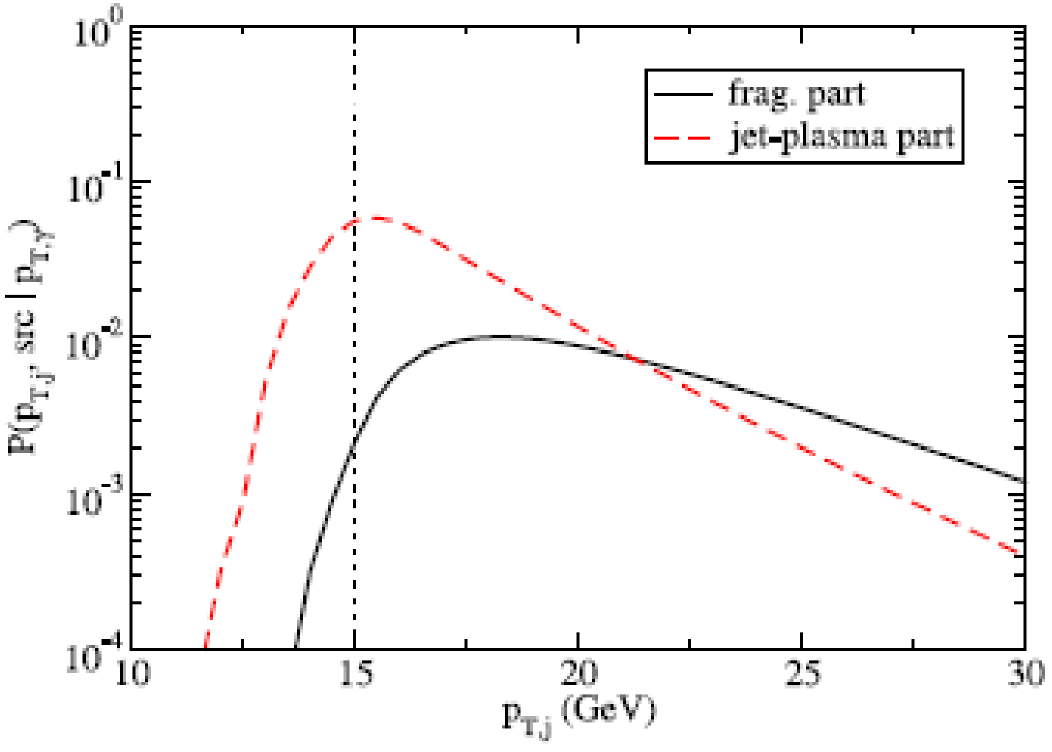


Fig. 4.1 The contributions from fragmentation photon and jet–plasma photon parts to the initial jet momentum distribution at the production time when we trigger on a photon with momentum $p_T^\gamma = 15$ GeV in most central Au + Au collisions at RHIC

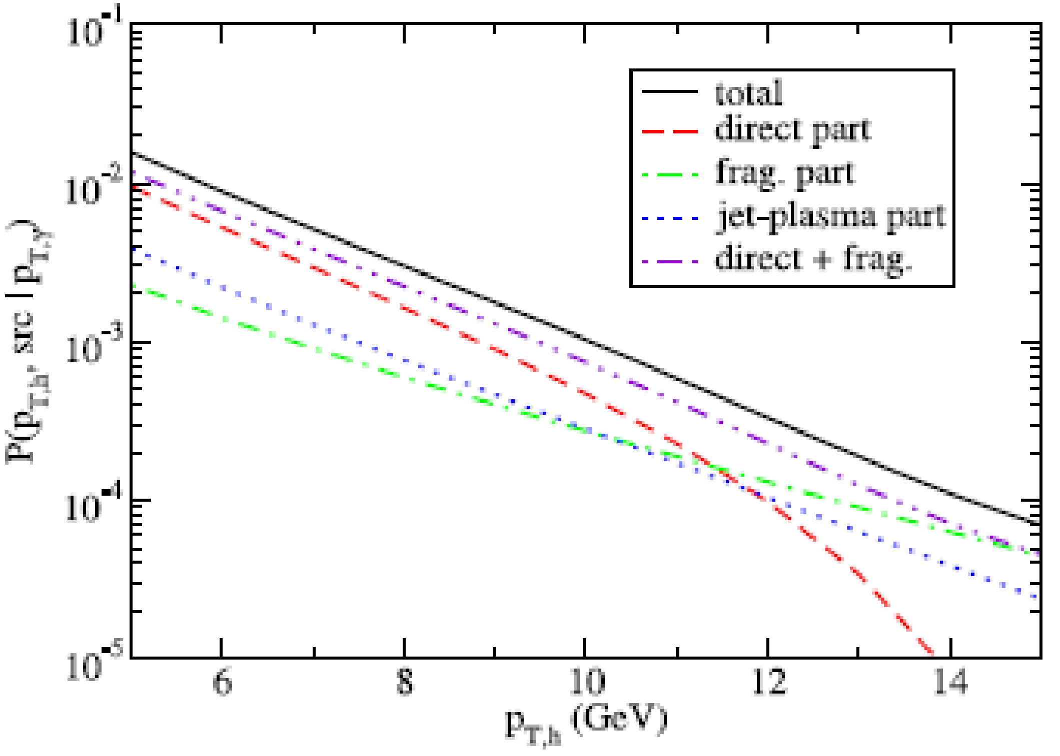
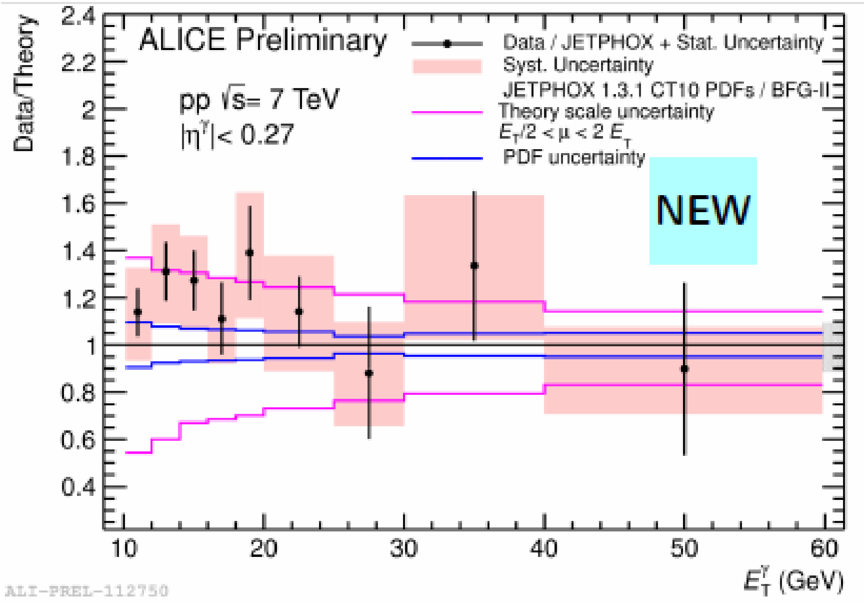


Fig. 4.2 Various contributions to per-trigger yield of the away-side hadrons when we trigger a photon with momentum $p_T^\gamma = 15$ GeV in most central Au + Au collisions at RHIC

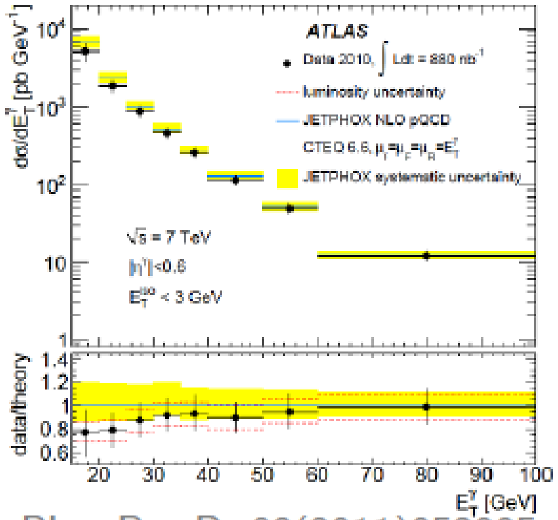
High p_T photons in p+p vs theory (new news)

(Slide from M. Germain, QM'17)

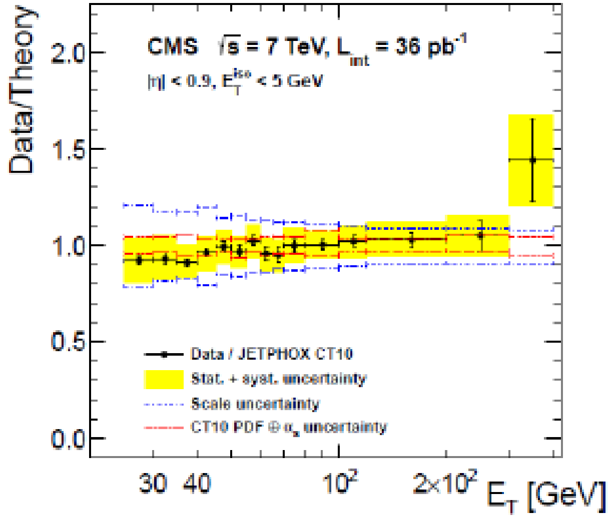
Isolated photons
Future reference for Pb+Pb



- Reasonable agreement with CMS, ATLAS in overlapping region



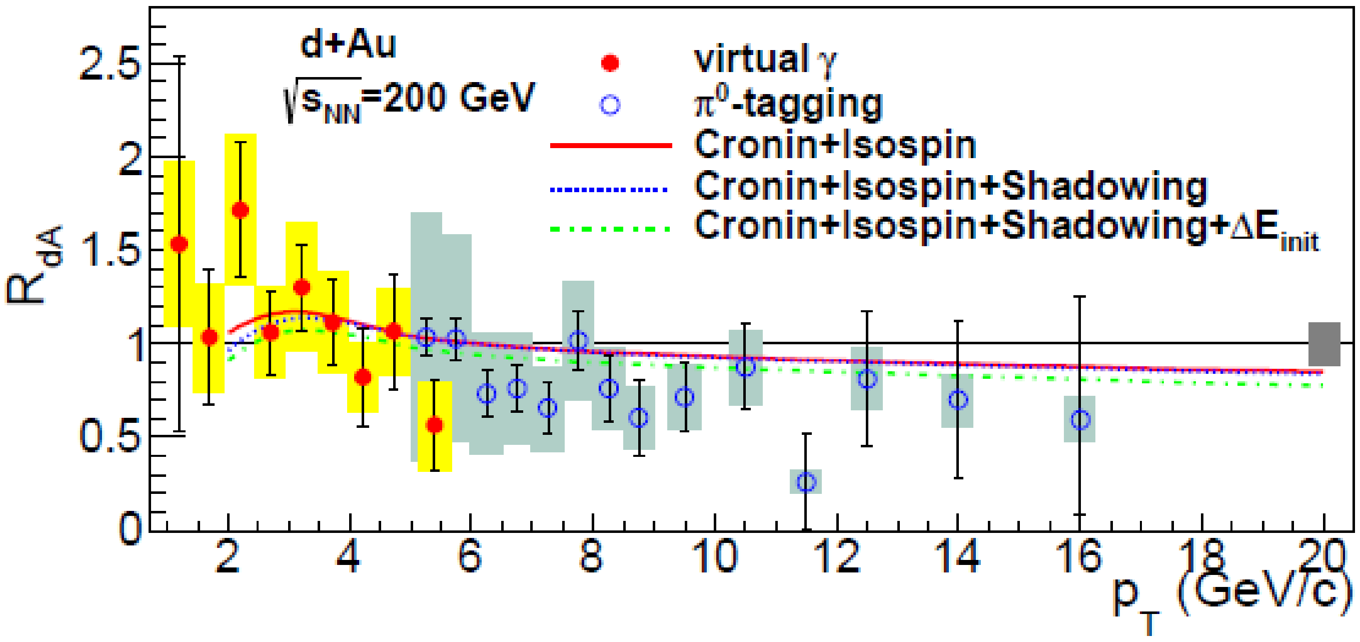
Phys.Rev.D. 83(2011)052005



Phys.Rev.D. 84(2011)052011

High p_T photons in asymmetric collisions

PHENIX (PRC 87, 054904 (2013))



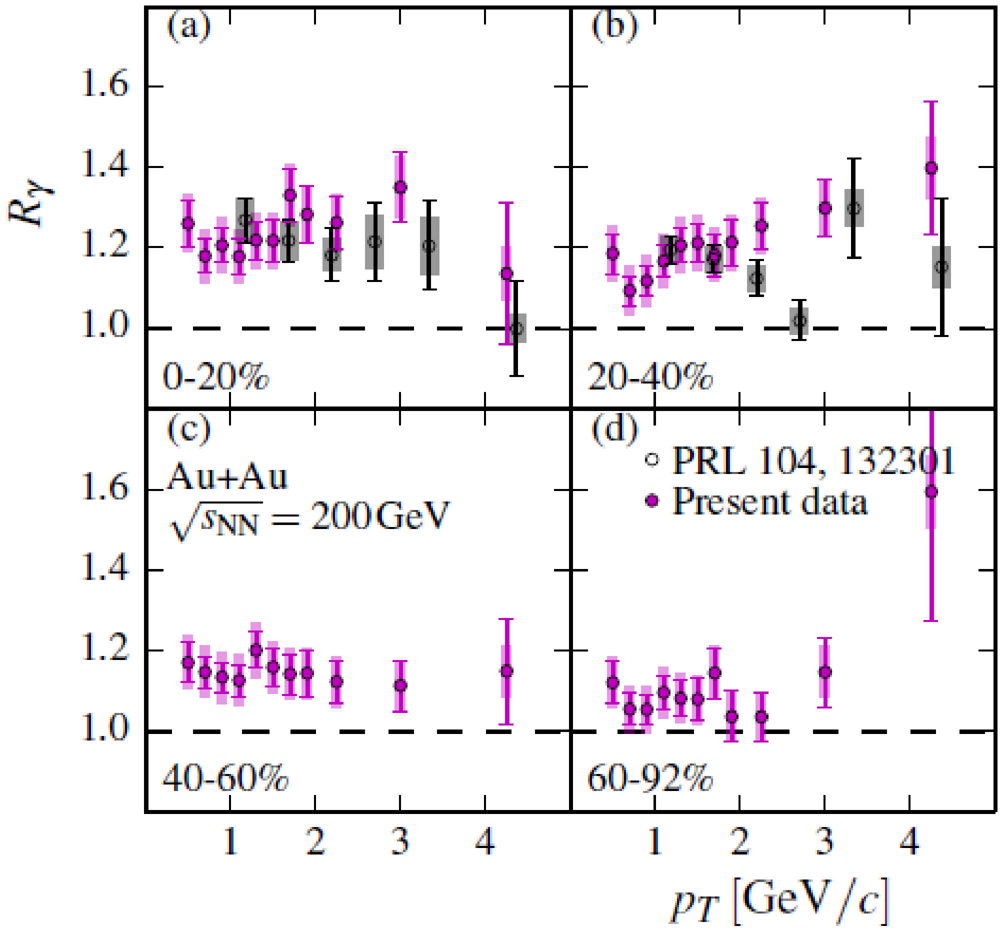
With all the issues with determining "centrality" (rather than just event activity) *can direct photons be an a posteriori test of geometry selection in very asymmetric collisions?*

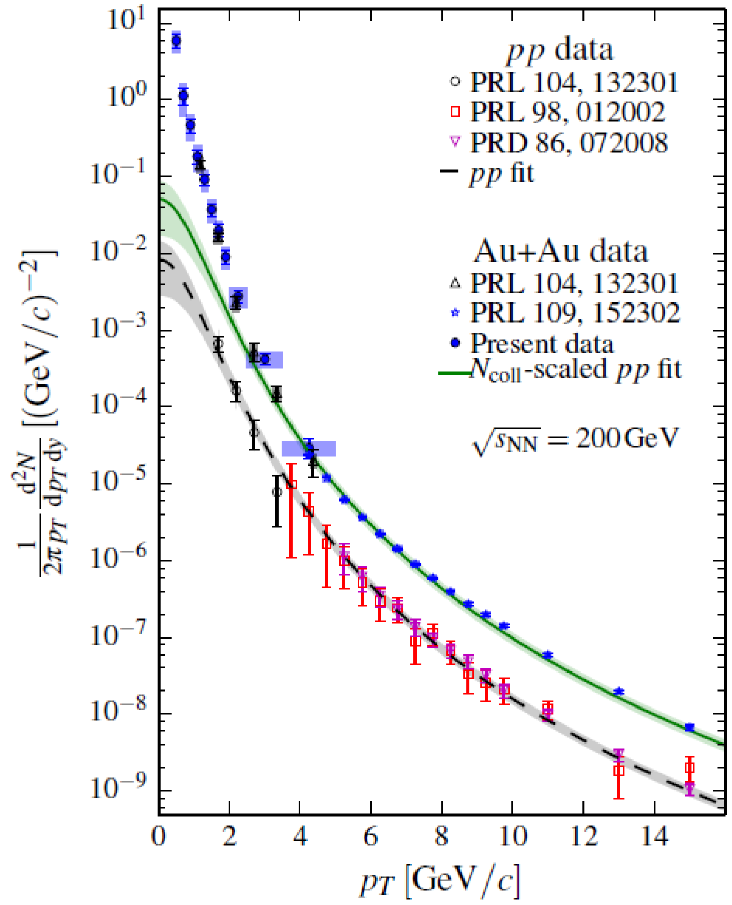
(1702.00542)

Low p_T (thermal???) photons

$$R_\gamma = N_\gamma^{incl} / N_\gamma^{hadron}$$

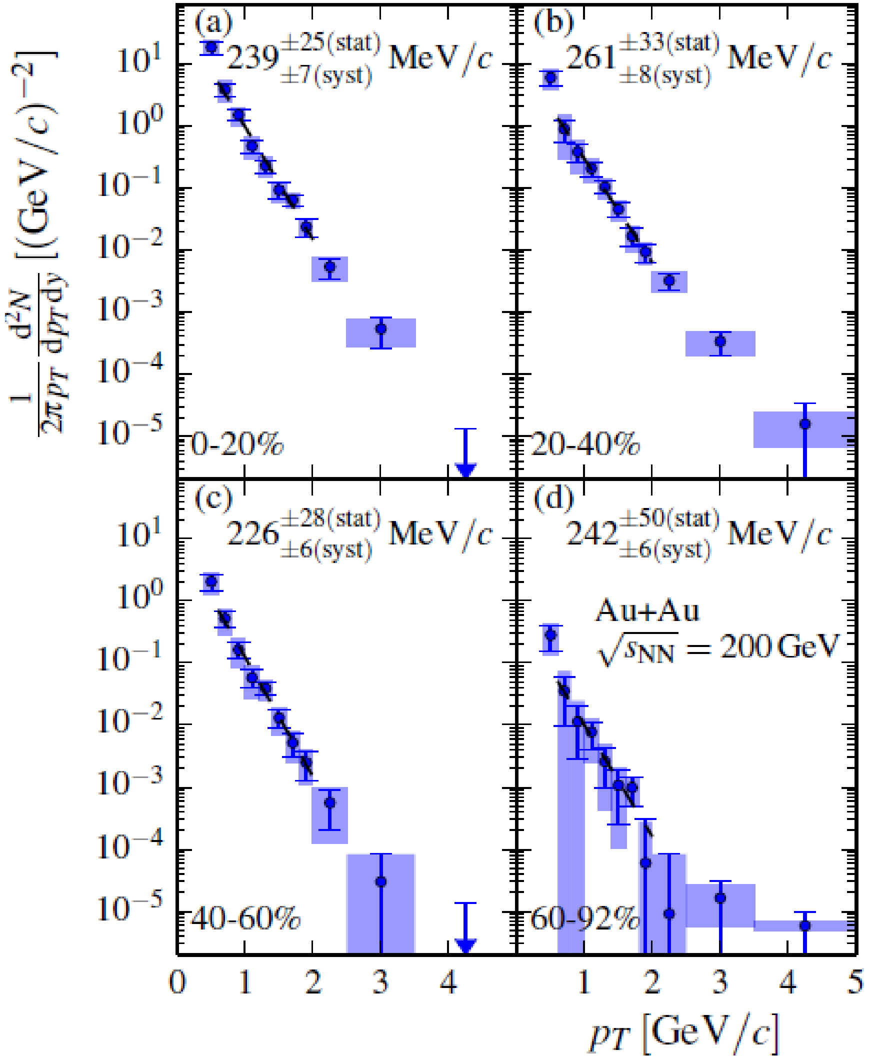
$$\gamma^{direct} = (R_\gamma - 1) \times \gamma^{hadron}$$

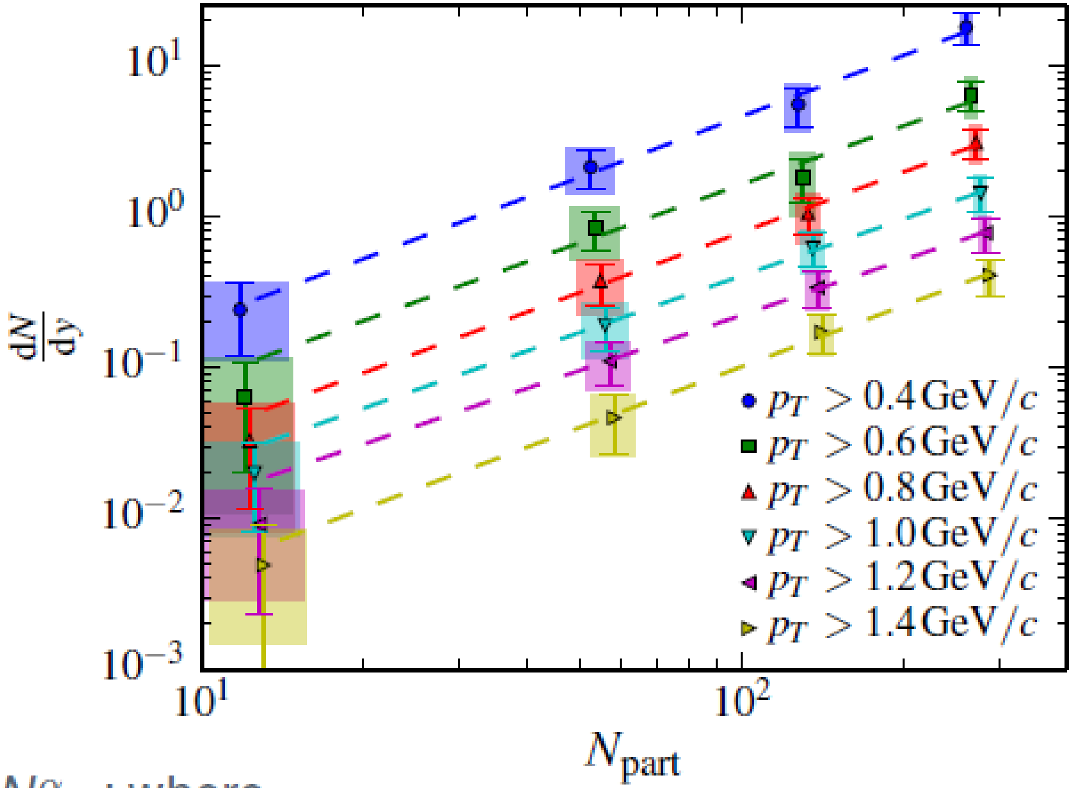




Low p_T (thermal???) photons – before QM'17

PHENIX (PRC 91 064904 (2015))





Yield $\propto N_{part}^{\alpha}$; where $\alpha =$
$1.38 \pm 0.03(stat) \pm 0.07(sys)$

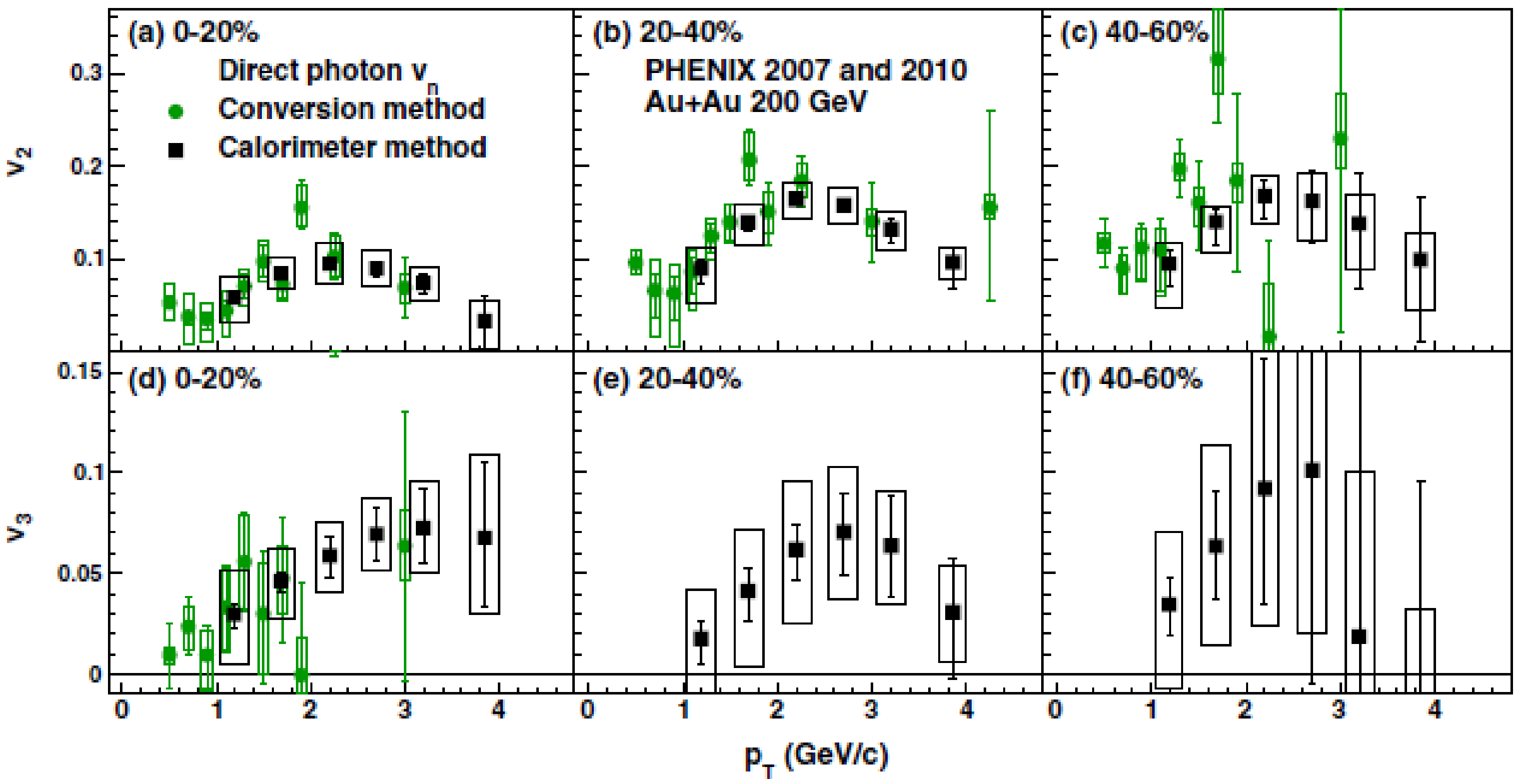
Yield grows faster than N_{part}

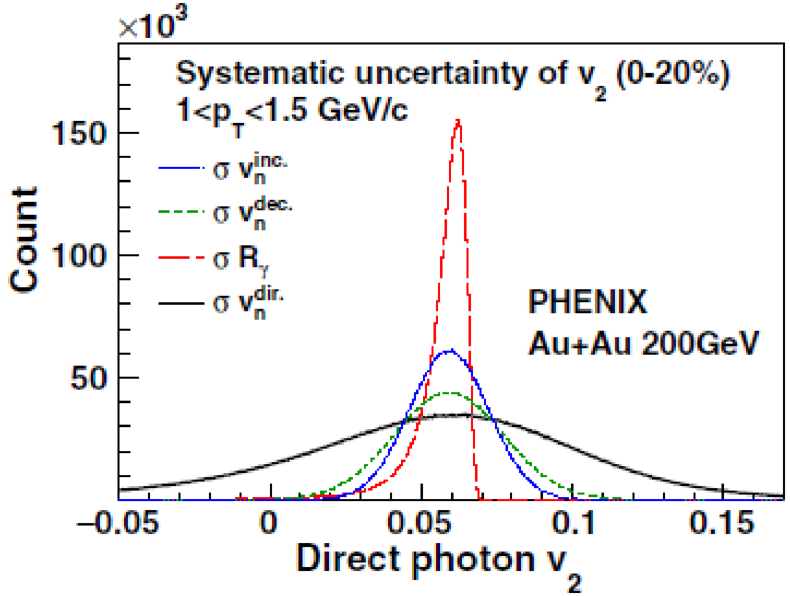
$T_{eff} = 0.244 \pm 0.028 \pm 0.007$ GeV

Low p_T (thermal???) photons – before QM'17

PHENIX (PRC 94, 064901 (2016))

$$v_n^{\mathrm{dir}} = \frac{R_\gamma v_n^{\mathrm{inc}} - v_n^{\mathrm{dec}}}{R_\gamma - 1}$$





Caveat: complicated systematic uncertainties!
(I'm deliberately not showing the ALICE preliminary, respecting their decision not to publish it so far.)

Direct photon puzzle (low p_T)
high yield *and* high flow?

Yields and flow at the same time? – "fireball"

H. vHees et al., PRC 84, 054906(2011)

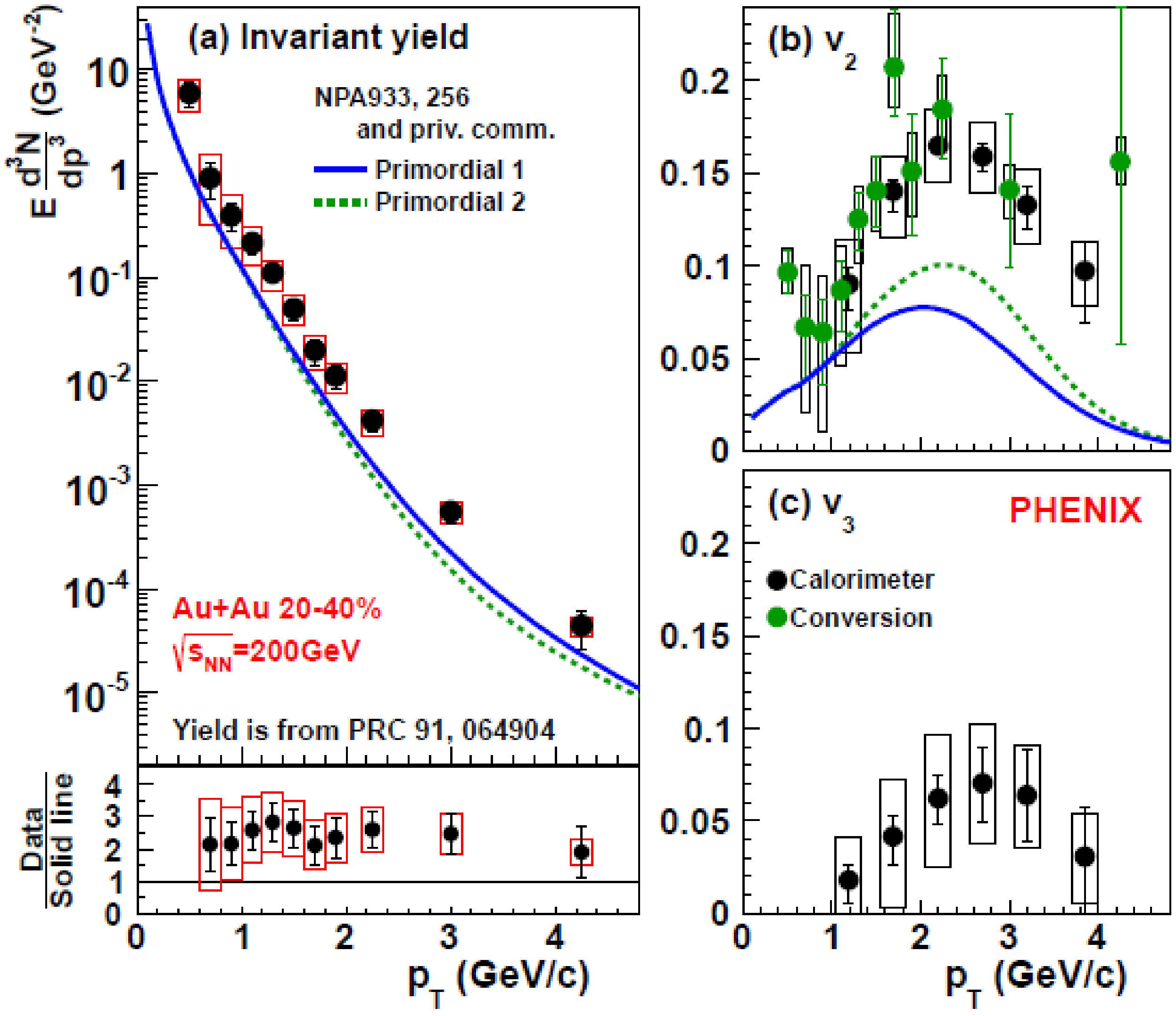
Included Hadron Gas interaction (HG), QGP and pQCD contribution with fireball time profile

HG includes resonance decays and hadron-hadron scattering that produce photons

Blue shift of the HG spectra is included

Two lines in the v_2 calculation correspond to different parameterization of pQCD component

No v_3 (should be possible)



Yields and flow at the same time? -- “semi-QGP”

Photons from semi-QGP is assessed together with HG

C. Gale et al., PRL114, 072301 + priv.comm. with Y Hidaka and J-F. Paquet

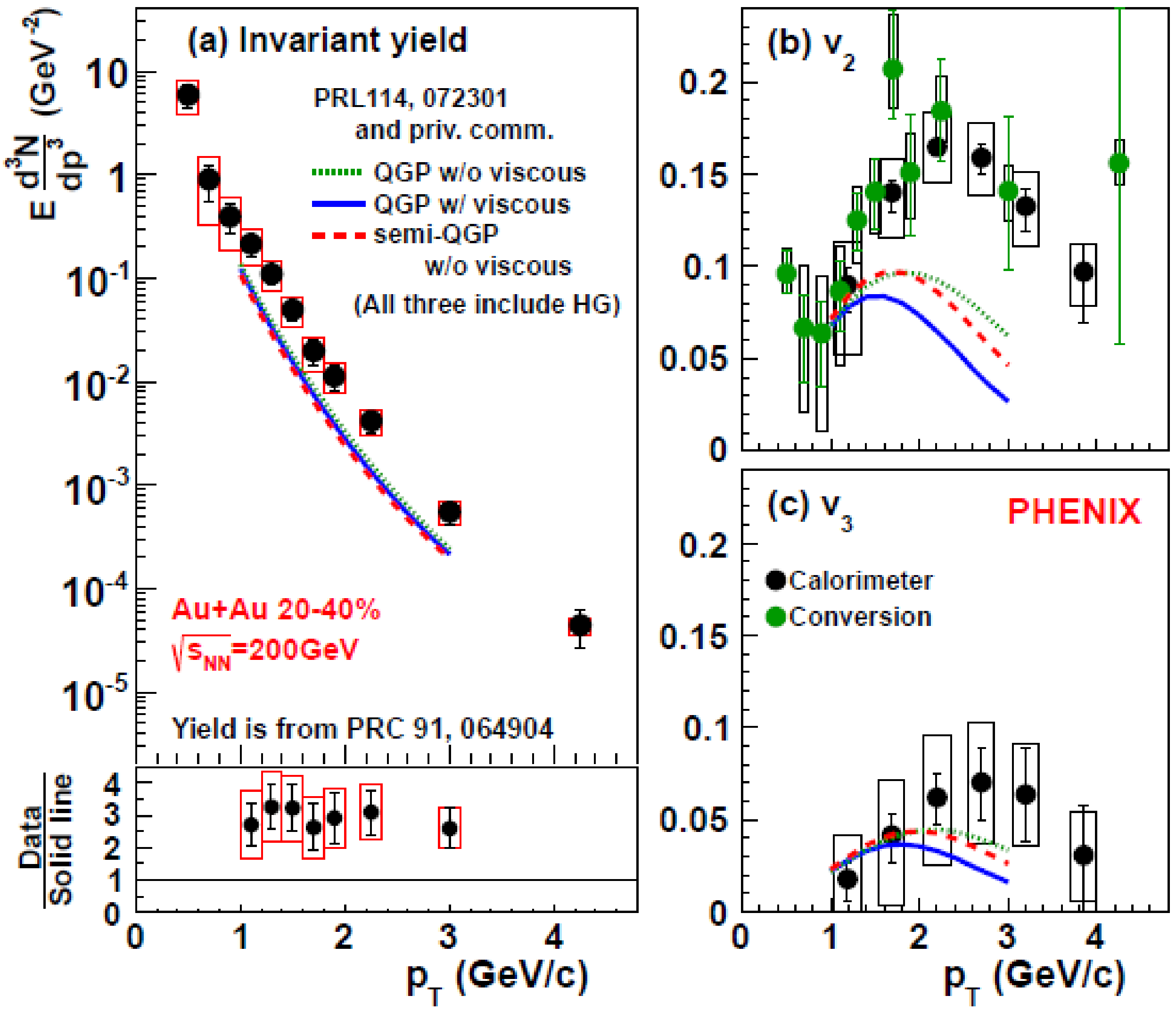
Semi-QGP: reduced photon rates around T_c

Photon contributions are evaluated at each T

Annihilation and Compton processes around the hadronization time are naturally included

Add some v_2 and v_3 on top of HG contribution

HG contribution is large (~80% of total v_2 is from HG)



Yields and flow at the same time? -- "PHSD"

Parton-hadron string dynamics

O. Linnyk et al., PRC 89, 034908(2014)

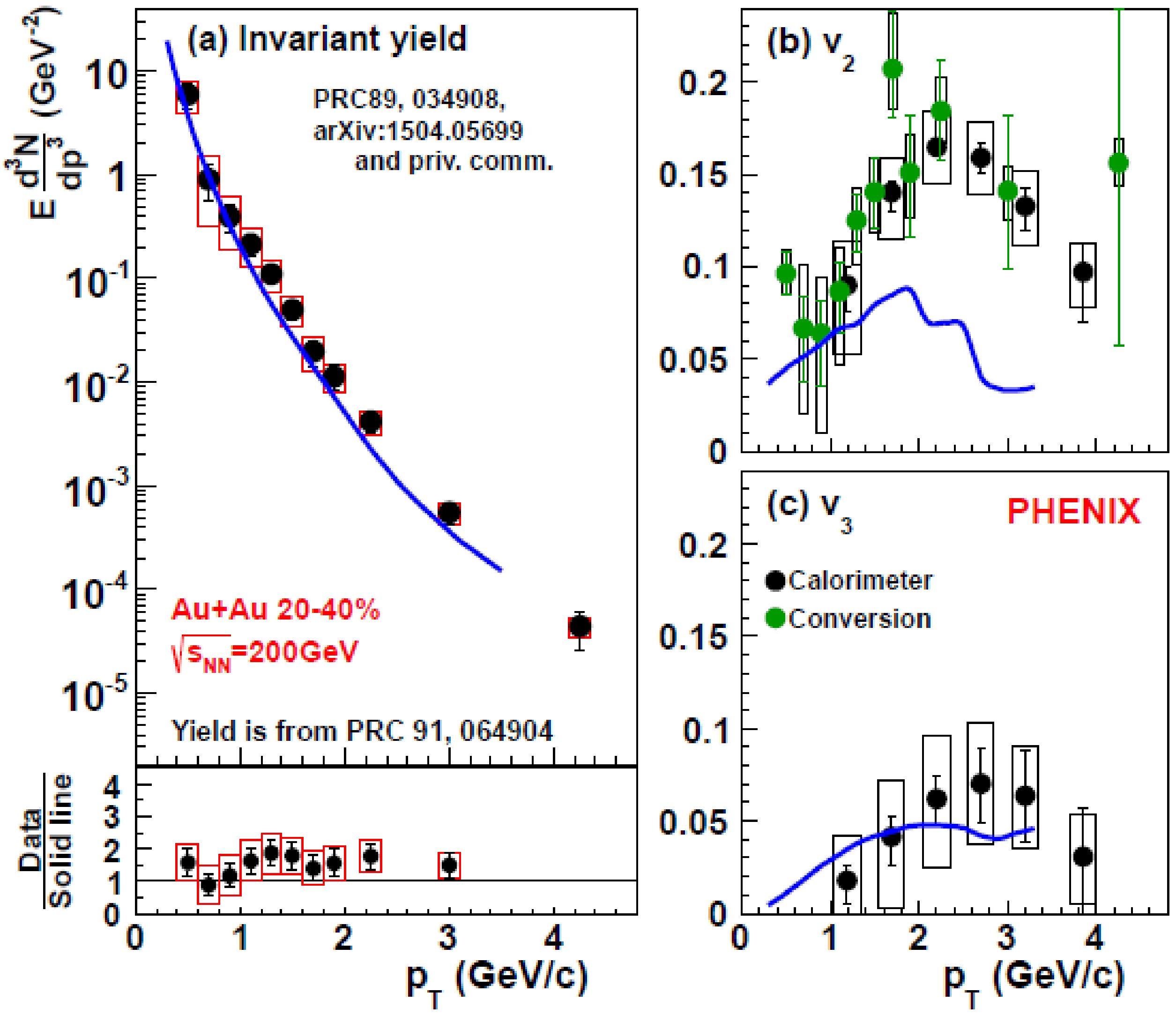
Including as much hadron-hadron interactions as possible in HG phase, using Boltzmann transport

Bremsstrahlung important

Thermal photon from QGP is also included

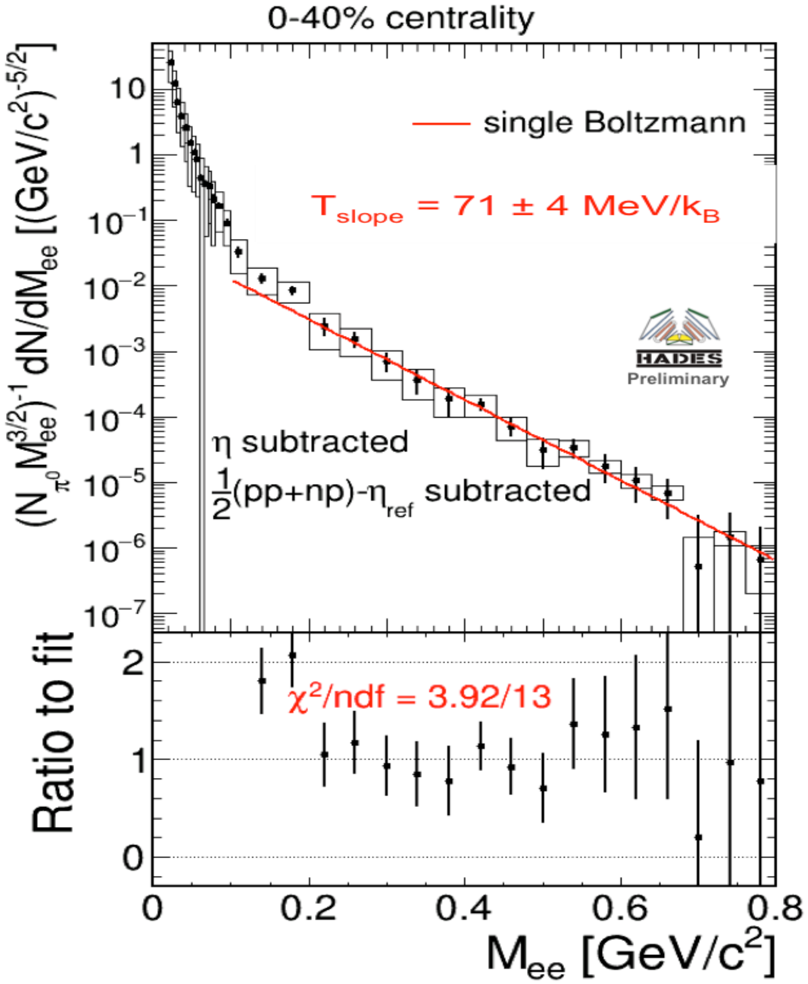
qg, qbar incoherent scattering + LPM

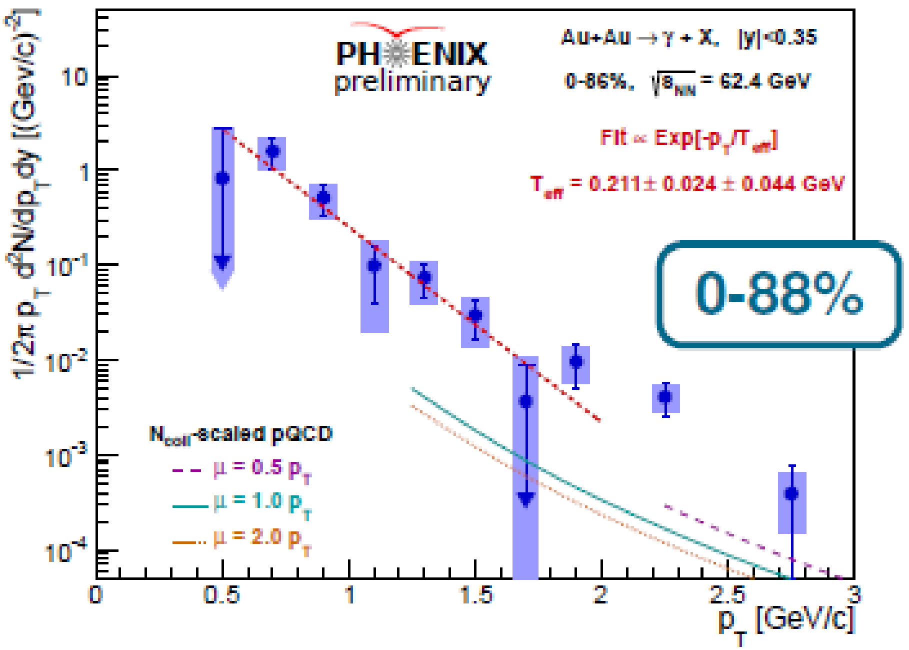
Latest paper (PRC 92 054914 (2015)) describes v_3 for 0-20% and 20-40% quite well

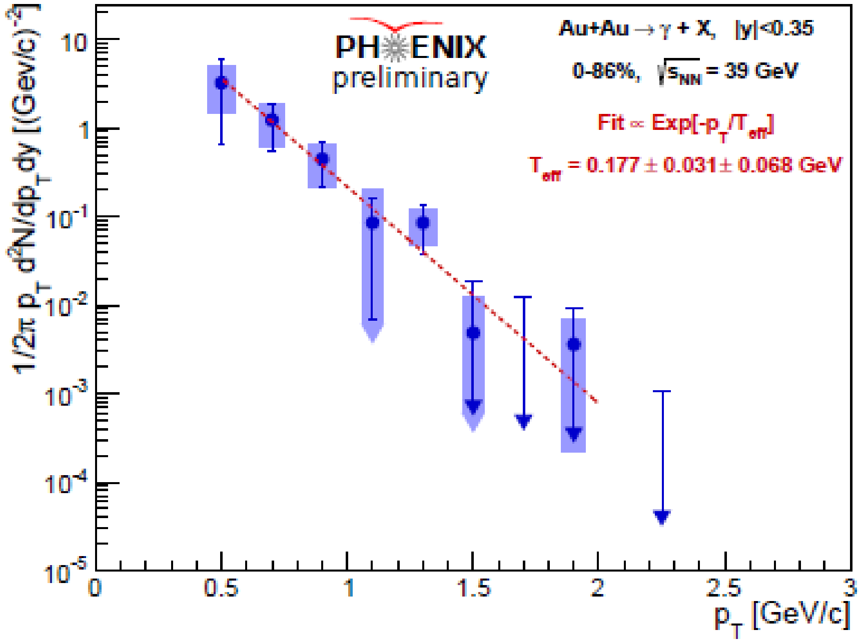


Low p_T (thermal???) γ^*,γ – at QM'17

HADES



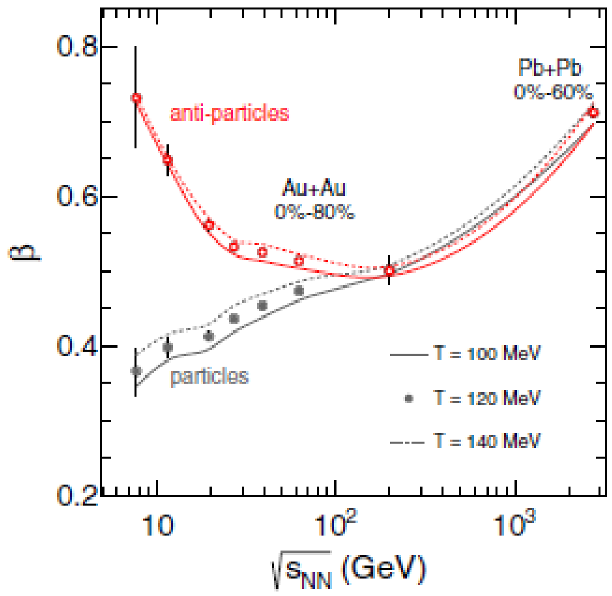


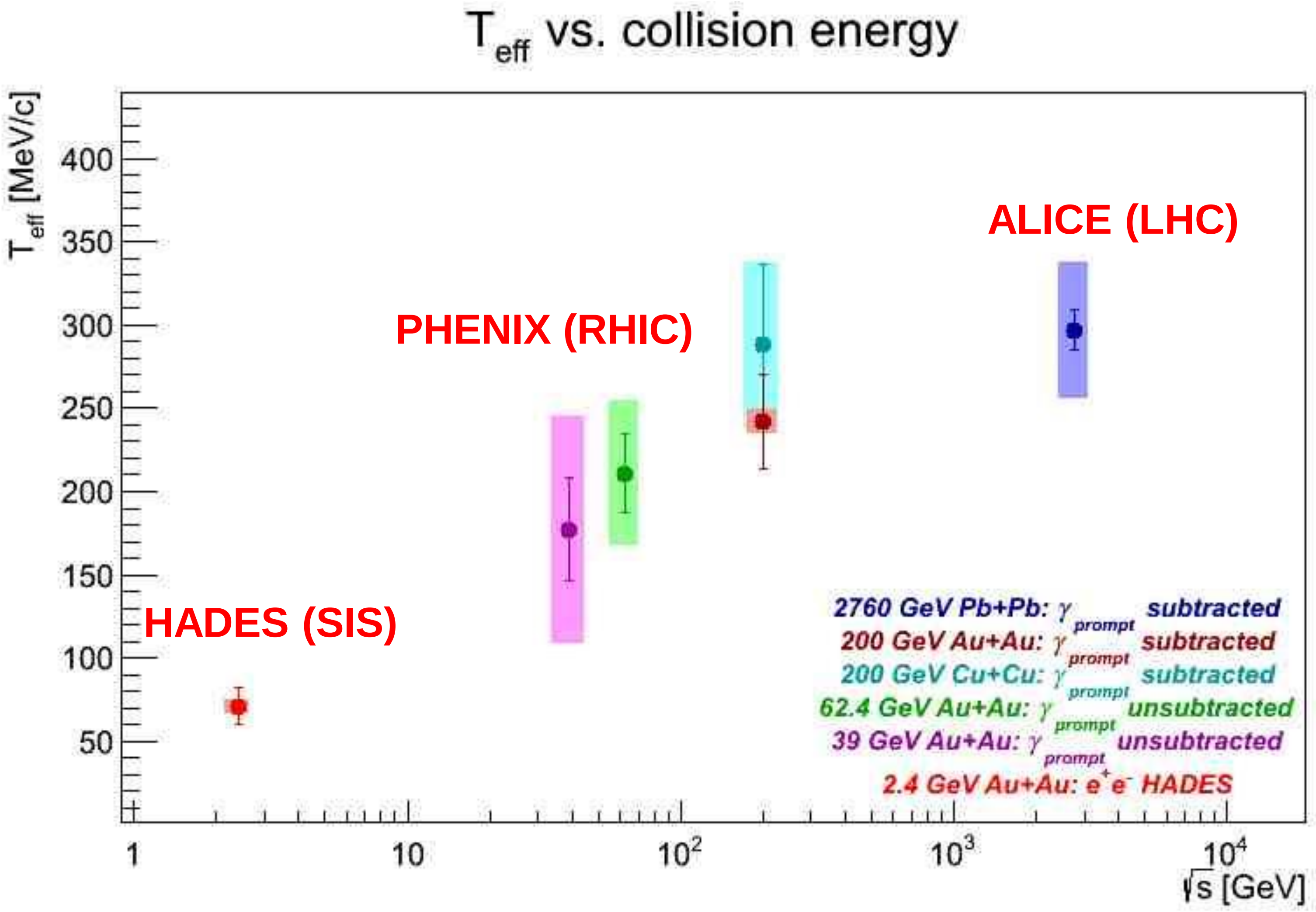


T_{eff} (1/slope) in the "thermal" region

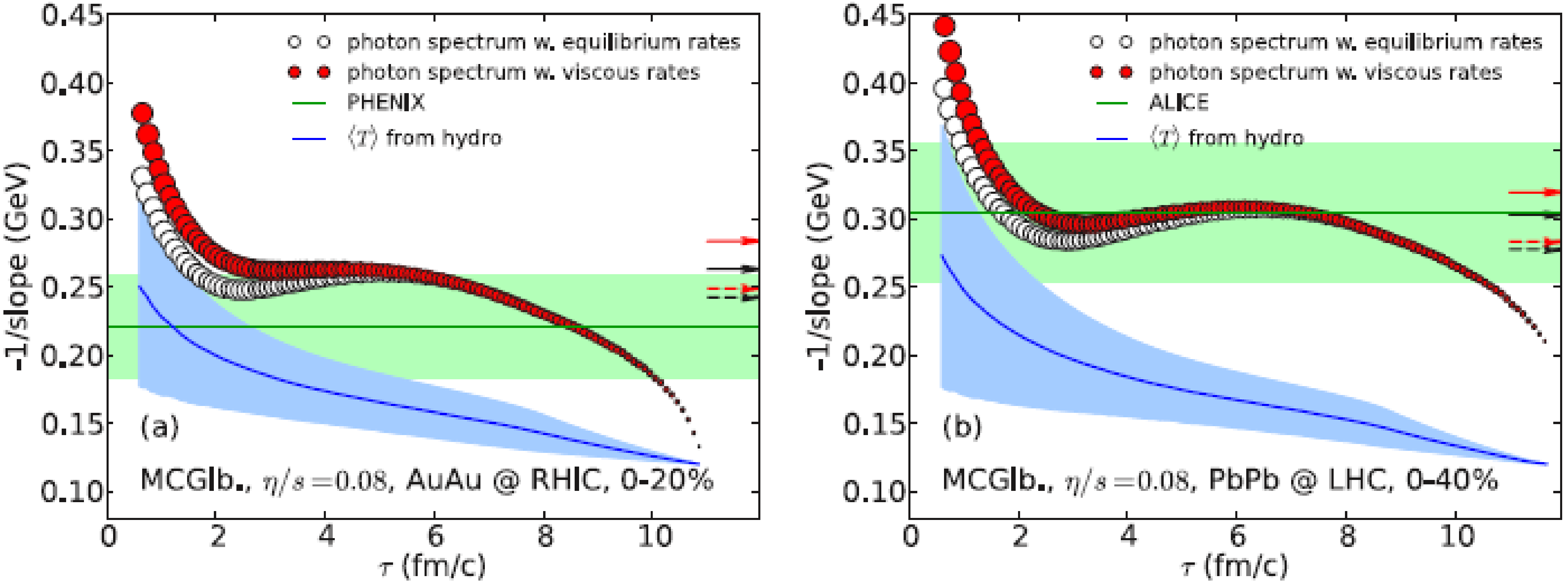
Tantalizing – but there are many things to consider
- blue shift (radial flow)
- relative contribution from various stages
(see next slide)

(PRC 91, 024903 (2015))





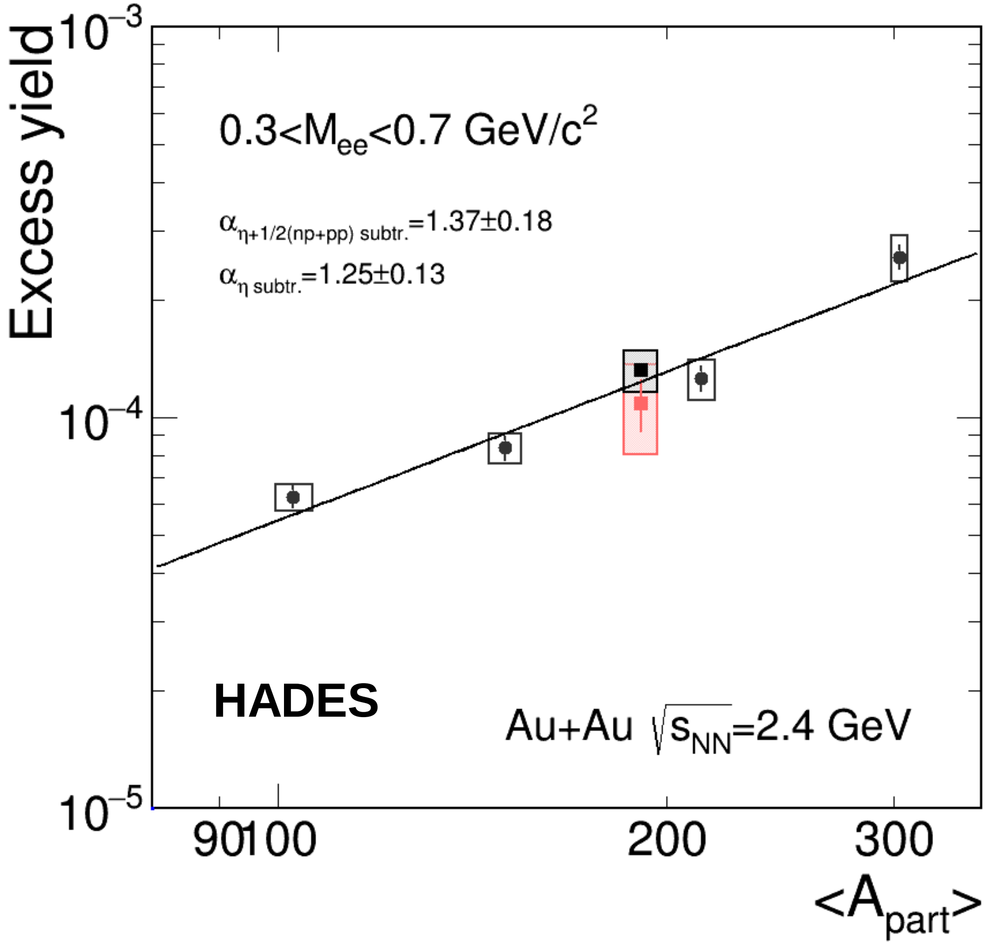
T_{eff} (1/slope) in the "thermal" region

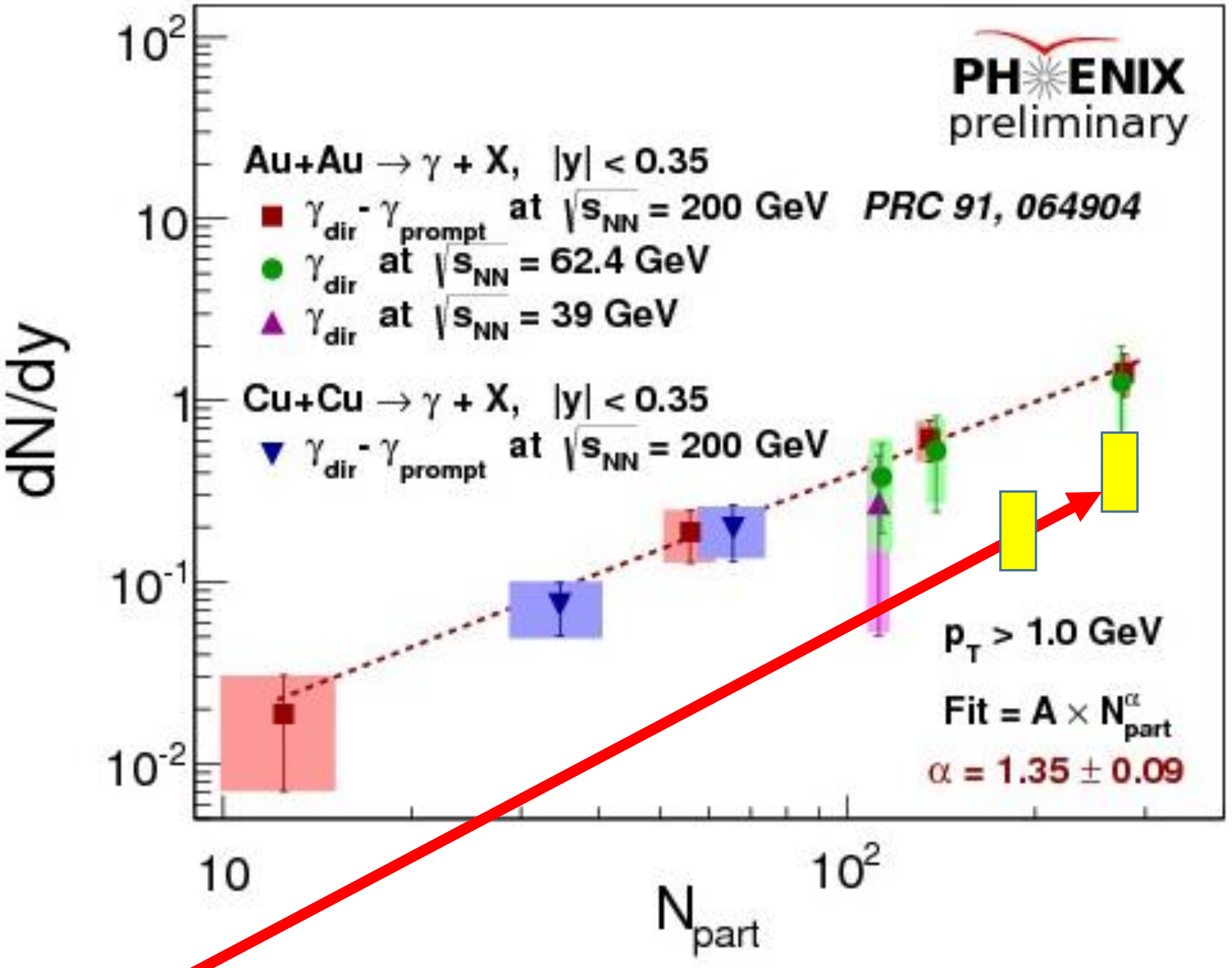


PRC 89, 044910 (2014), Shen, Heinz, Paquet, Gale

Integrated yield vs N_{part}, different energies

Why does one α fit all???



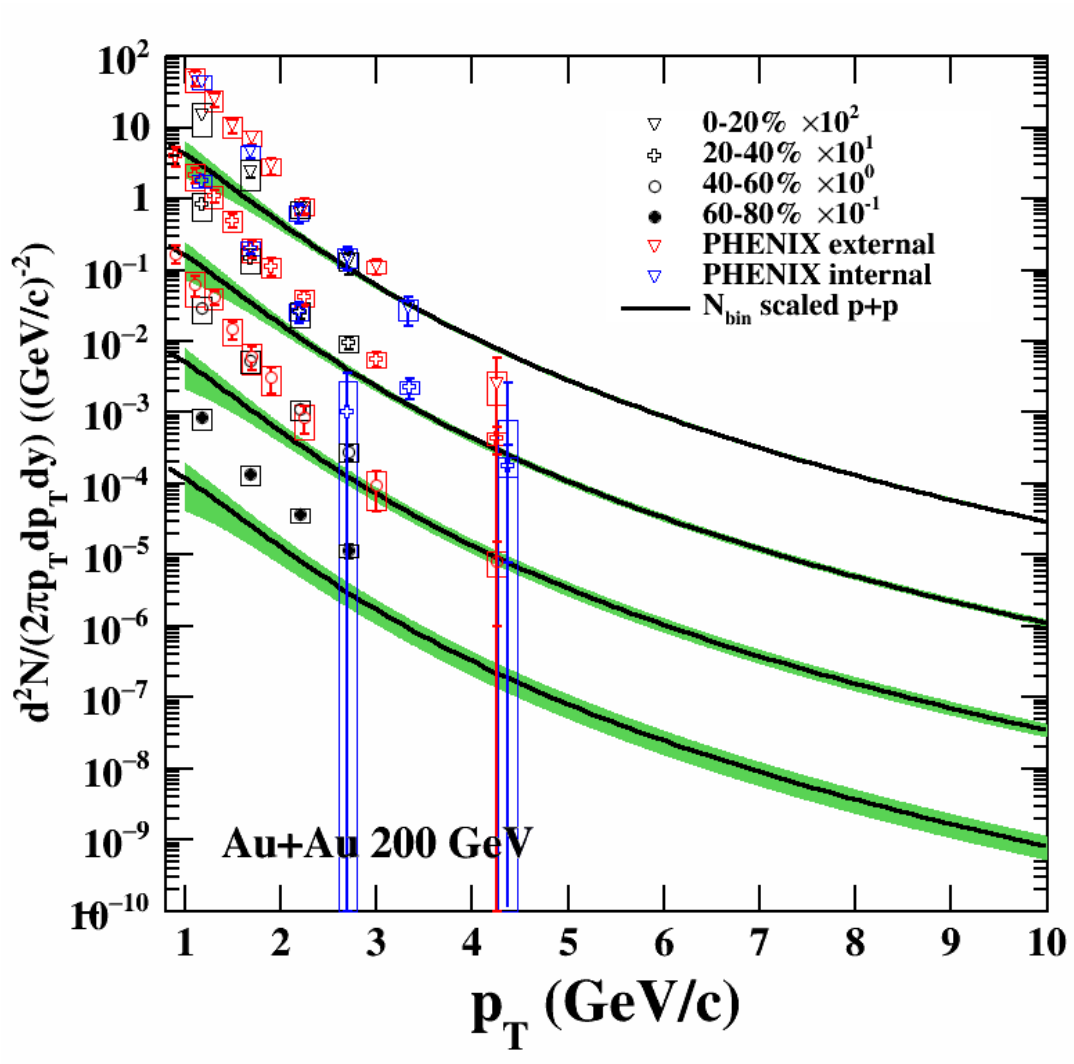


1701.05064 "bottom-up" thermalization
dN/dy only, no spectra or flow yet

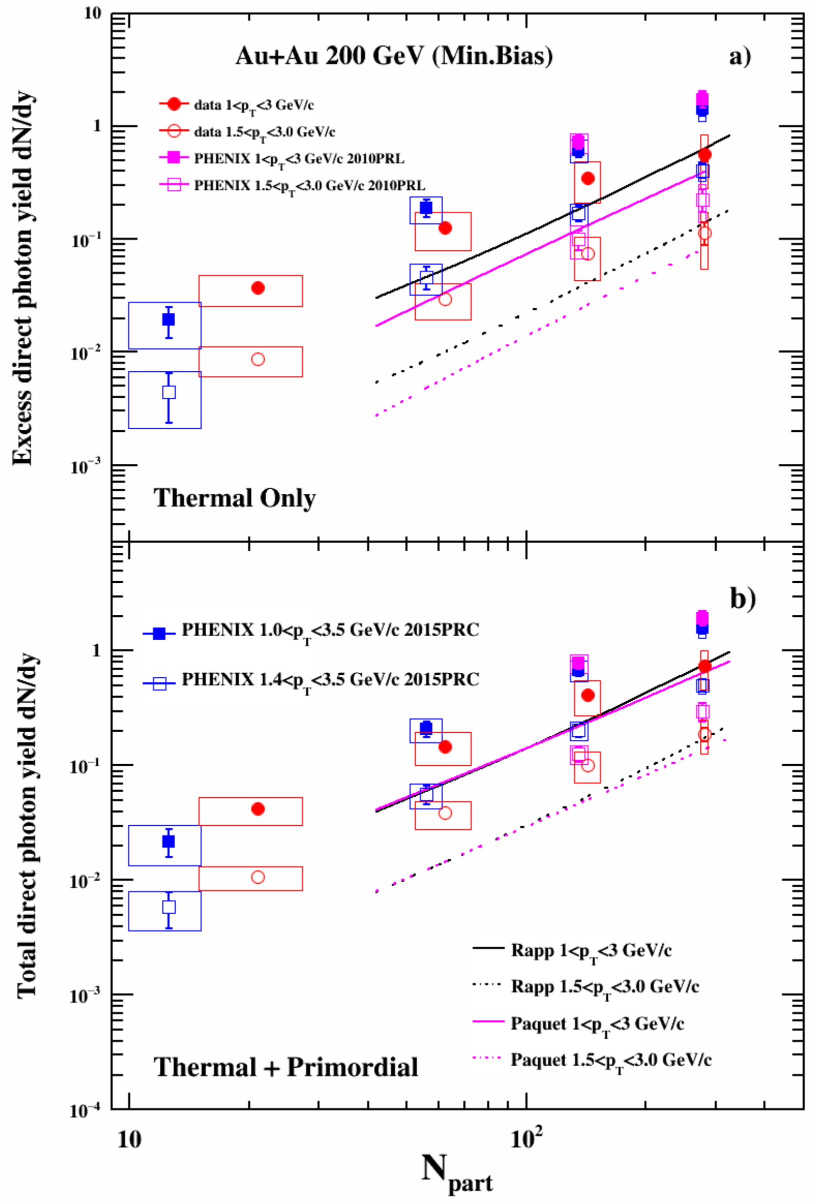
$$(dN_{ch}/d\eta)/(0.5N_{part})(\sqrt{s_{NN}}) \propto e^{b\times log(\sqrt{s_{NN}})}$$

A currently open issue

STAR (1607.01447) vs PHENIX (PRL 104, 132301 (2010) and PRC 91, 064904 (2015))



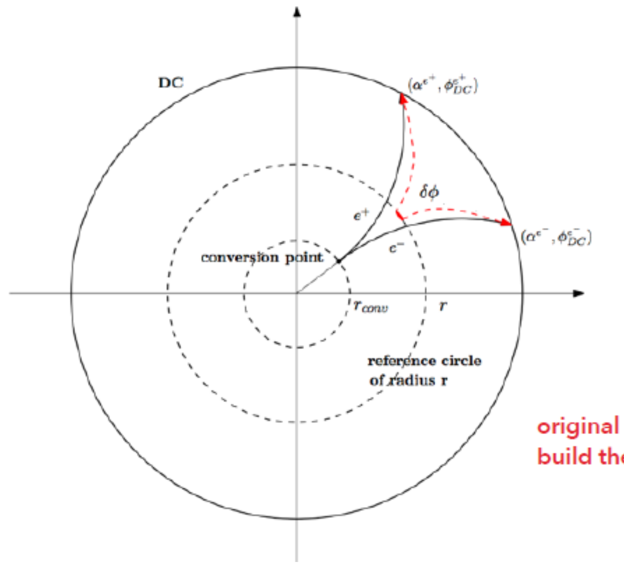
(under investigation)



Low p_T (thermal???) photons – after QM'17

New technique that doesn't rely on the knowledge of the actual conversion point

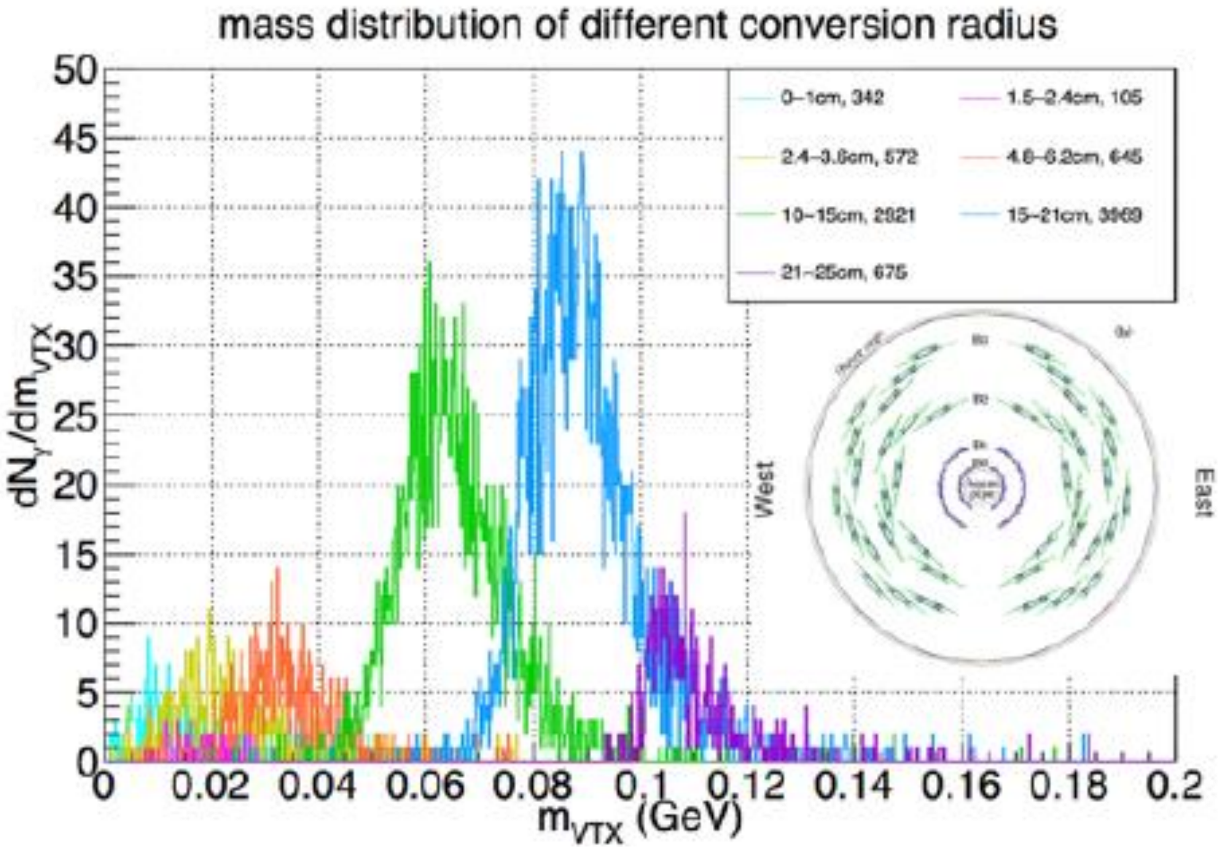
- lookup table $\{\alpha, p_T, r_{conv}, \phi_{conv}, \phi_{DC}\}$
- interpolate p_T, ϕ_{conv} as a function of $(\alpha, \phi_{DC}, r_{conv})$
- solve for conversion point & pT



- a pair of tracks, assuming from radius r
- only at true conversion radius, the tracks intersect each other

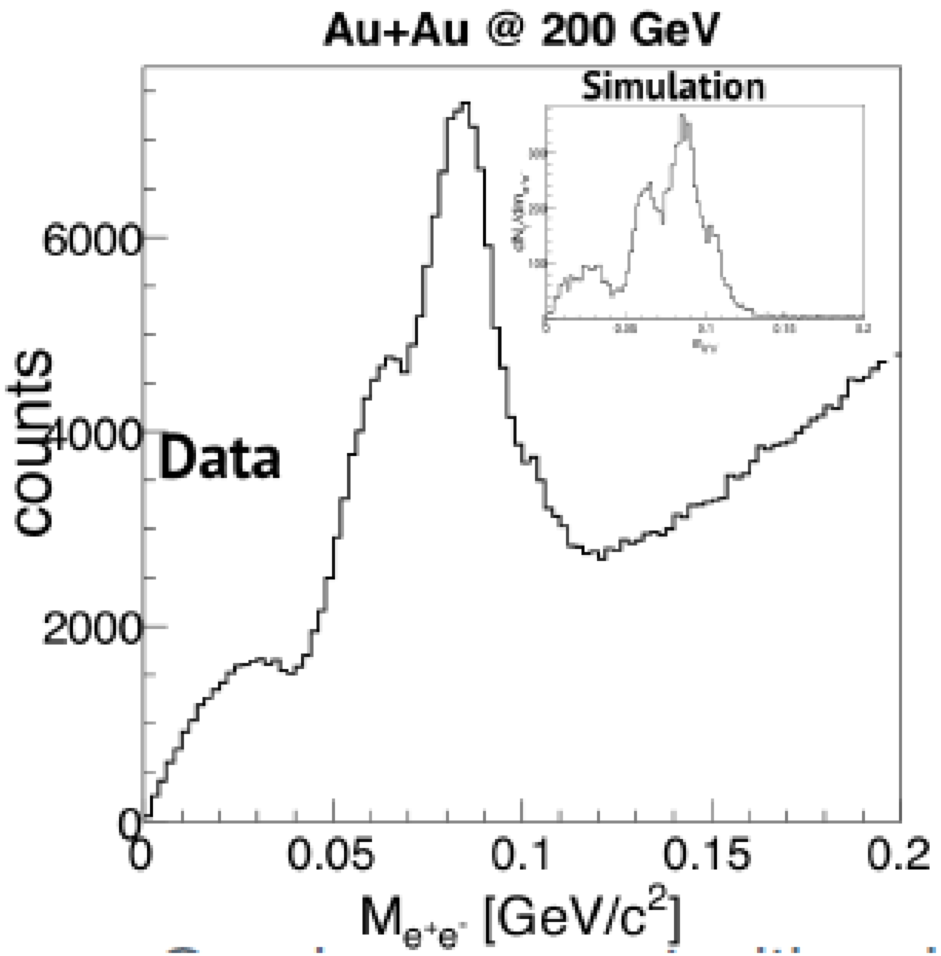
$r_{conv} \longrightarrow p_T, \phi_{conv}$

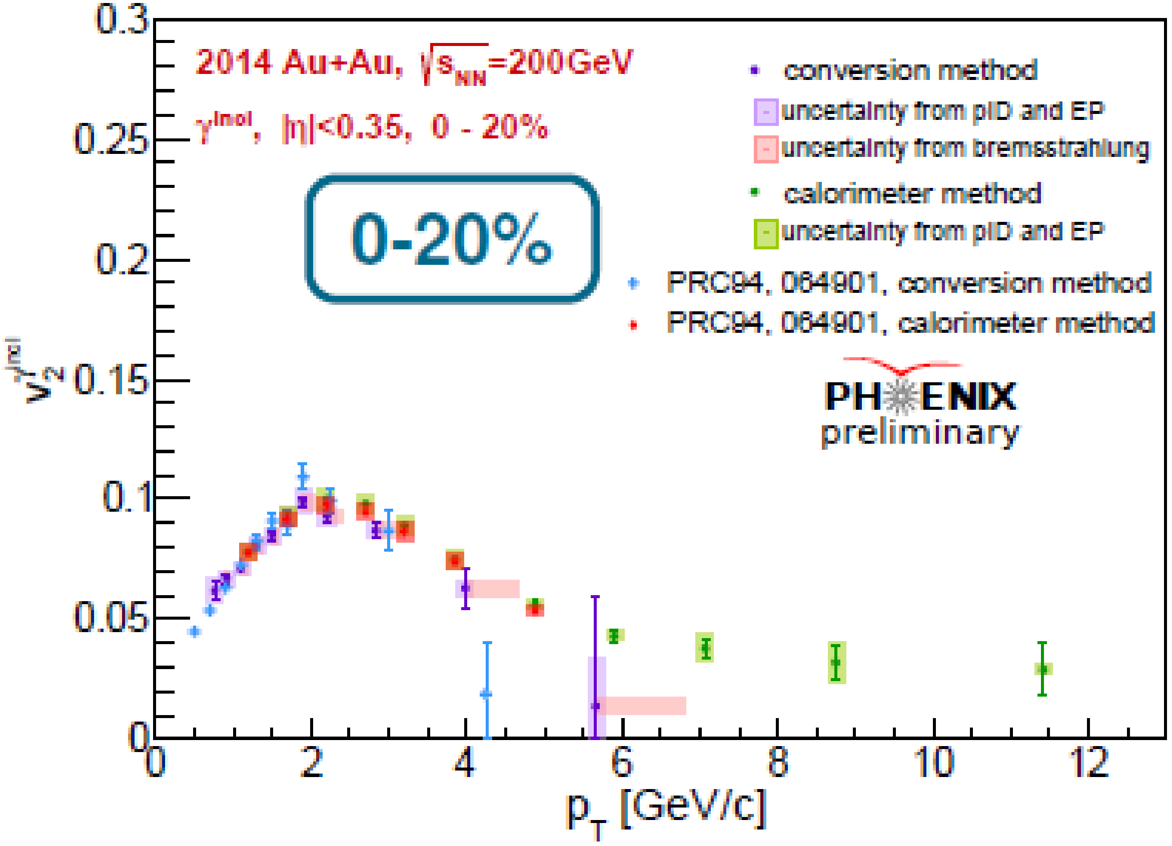
original implementation is using mathematica to build the lookup table with only 2D field map



Photon flow at low p_T – much more accurately

PHENIX, external conversion on the VTX layers – so far only 25% of the available 2014 statistics





With higher accuracy: photon v_2/v_3 as measure of time-dependence of η/s

NPA 932 (2014) 184

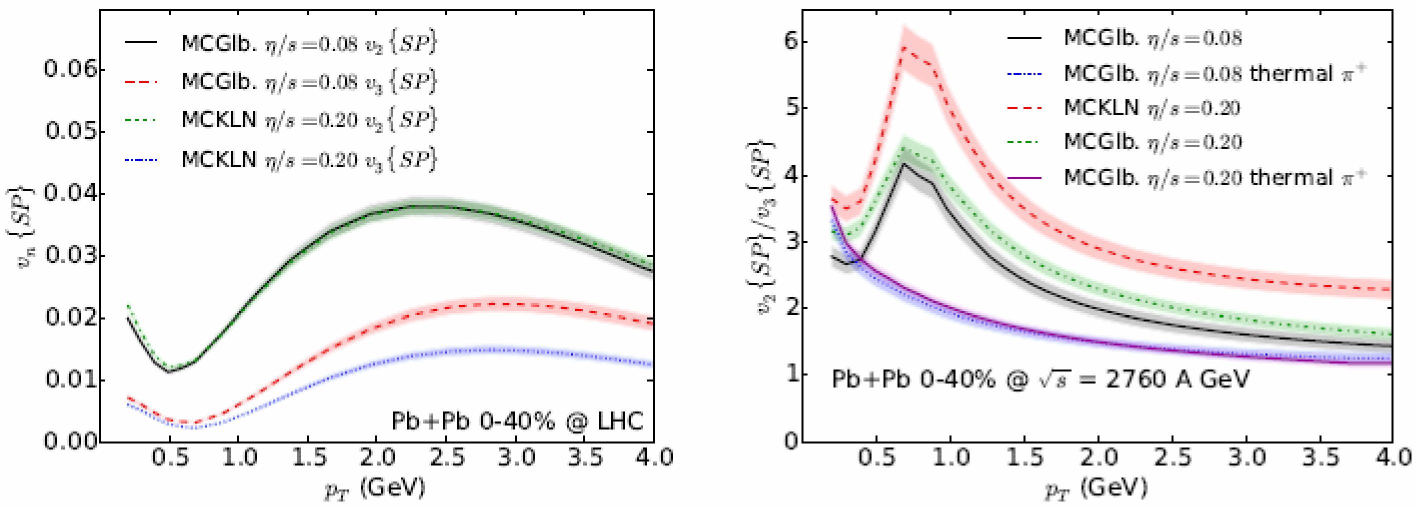
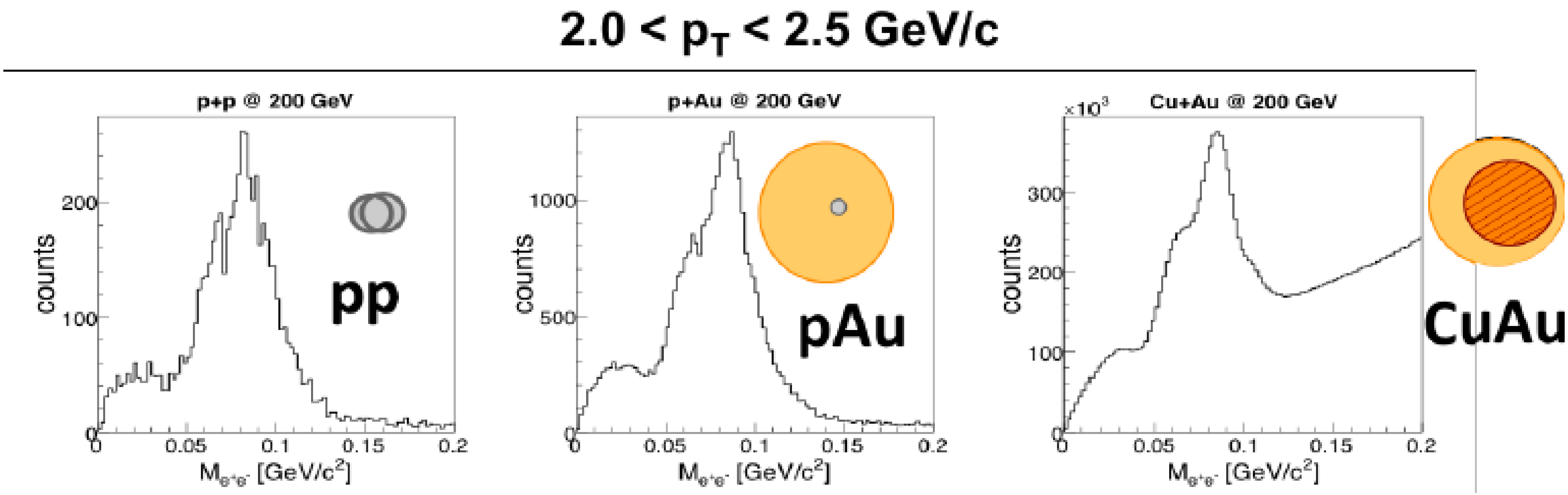


Figure 3. Left panel: p_T-differential $v_{2,3}$\{SP\} of thermal photons at 0-40% centrality in Pb + Pb collisions at $\sqrt{s} = 2.76\ A$ TeV. Right panel: The corresponding ratio v_2\{SP\}/v_3\{SP\} as a function of p_T compared with the same ratio for thermal π^+.

State-of-the-art calculations of thermal photon anisotropic flow, v_n\{SP\} ($n = 2, 3$), use event-by-event viscous hydrodynamic simulations to account for event-by-event quantum fluctuations in the initial state. Shear viscosity suppresses photon v_n\{SP\}, with viscous corrections to the photon production rates dominating this suppression. For both the p_T-integrated and p_T-differential anisotropic flows, the ratio v_2^γ\{SP\}/v_3^γ\{SP\} shows stronger sensitivity to the specific shear viscosity of the QGP for thermal photons than for charged hadrons. This ratio increases with η/s because the viscous suppression of v_n increases with the harmonic order n. Since the ratio v_2^γ\{SP\}/v_3^γ\{SP\} is insensitive to photon sources that carry zero anisotropic flow, such as prompt photons, the experimental measurements of this ratio for direct photons will shed new and more direct light on the specific shear viscosity of the thermal medium formed after the end of prompt photon emission, but well before most of finally emitted hadrons are set free.

Low p_T (thermal???) photons – after QM'17

Thermal photons from more (asymmetric) systems, d+Au energy scan – coming soon!



The honest slide

The main problem is at the heart of the “direct photon promise”:

- while *hadronic* observables mostly *constrain* only your *final state* (but not much the dynamics how you got there) *direct photons* force you to get the *entire evolution* – rates and expansion – right at the same time

- nevertheless, any scenario in the end should explain *hadrons and photons* simultaneously!

Initial state effects – including nPDFs, pre-equilibrium processes, glasma, etc. became important players

Radiation from the *hadron phase* (even after decoupling) emphasized more and more

Role of the QGP deprecated???

- that’s quite ironic: once upon a time we thought it is going to be the dominant source

Whatever the truth, current mainstream models emphasize

- either very early asymmetries and expansion, or very late production, or a combination of both

Summary

Reasonable understanding at high p_T, calibrating parton energy ("golden channel") → ***essentially yes***

Resolving ambiguities in "centrality" (geometry vs event activity) for very asymmetric systems → ***probably yes***

Coherent description of sources (rates) and system evolution at lower p_T, solving the "puzzle" → ***not there yet***

Precision, precision… (and system size scan, energy scan…)

Will there ever be an experiment really dedicated to electromagnetic probes?

Backup slides